TECHNICAL FEASIBILITY OF RESTORATION ACTIONS — CHAPTER 2

2.1 Overview of the Technical Feasibility Assessment

This chapter discusses the technical feasibility of restoration based on information both from actual oil discharge and non-oil restoration situations. It is restricted to technical and engineering issues. Scientific aspects of effectiveness and success are discussed in Chapter 3.

Exhibit 2.1 presents a simplified conceptual overview of potential restoration alternatives and actions. The analysis of technical feasibility was performed for over 30 habitat types. However, conceptually, these habitat types used in Exhibit 2.1 can be categorized as follows:

- Wetlands;
- Biologically structured habitats (e.g., oyster reefs, coral reefs);
- Shorelines; and
- Open water.

The information in this document concentrates on the primary restoration actions for the various habitat types, as well as for categories of biological natural resources (i.e., species groups). Many of the primary restoration actions are also applicable to replacement. For instance, replanting of saltmarshes can be conducted either on- or off-site where an appropriate site exists. Also, habitat enhancement actions may be considered primary restoration actions for the habitats and for individual biological resources that use the habitat.

It was found that a coherent analysis of feasibility required that information from non-oil situations be used to supplement information from oil discharge situations. For instance, saltmarsh restoration has been attempted in few instances after oil discharges. One of the key restoration actions is replanting of the marsh. However, the information available on the few oil discharge restoration attempts is not complete enough to provide an adequate understanding of the full range of factors related to the feasibility of saltmarsh replanting. Thus, the analysis of restoration in saltmarsh habitats includes a specific discussion of cases where restoration was attempted after an oil discharge, but is supplemented with the considerable body of information on saltmarsh replanting that was developed in conjunction with saltmarsh restoration after non-oil injury situations.

Exhibit 2.1 Simplified overview of restoration actions.

General Habitat Types	Habitat Restoration	Habitat Replacement/ Enhancement	Restocking (Primary Natural Resource Restoration)	Habitat Enhancement	Other
Wetlands Saltmarsh Mangrove swamp Freshwater wetlands	• Contaminant removal • Replanting	• Replanting • New wetland creation	• Possible for certain fish reptile and bird species	• Covered under habitat restoration or replacement	• Off-site out-of-kind actions • On or off-site management practices - Harvest alteration - Protecting endangered habitat - Improving recreational services - Preservation - Mitigation banking, etc.
Structured Habitats Vegetated beds Oyster reefs Coral reefs	• Replanting/ reconstruction	• Replanting/ reconstruction	• Limited application	• Generally not feasible	
Shorelines Intertidal Riverine Lacustrine	• Contaminant removal	• Generally not feasible	• Possible for certain birds and mammals	• Limited applicability	
Open Water Subtidal Riverine Lacustrine	• Contaminant removal	• Generally not feasible	• Possible for certain fish species	• Artifical reefs • Stream habitat structures • Fish passageway improvement	

The discussion of technical feasibility includes a description of restoration actions, and consideration of key factors associated with the effective implementation of the action. Factors considered include:

- The general state of feasibility as demonstrated in actual restoration situations;
- The availability of services, expertise, equipment, and materials to perform the action;
- Operational constraints that may inhibit implementation of the action in various situations; and
- The need for future restoration actions, as well as the capability to perform those efforts.

Please note that in this section, consideration of constraints are restricted to operational and technical implementation, not to how effective or successful the action is in the long run. Effectiveness and success is reviewed in detail in Chapter 3. Chapter 2 lays the groundwork for what actions are available for consideration. Effectiveness and success should be the ultimate criteria for choices made.

The technical feasibility of restoration actions contained in this section also takes into consideration the legal and regulatory constraints of the various restoration actions. These factors have a substantial impact on the viability of restoration actions at the site-specific level. At the generalized level addressed in this document, these factors are similar across many of the habitat types and restoration actions. For this reason, the legal and regulatory constraints are presented and key implications summarized in Section 2.5.

The analysis of feasibility of the restoration actions is arranged by habitat type, which are based on the classification presented in Cowardin et al. (1979) (see Section 1). However, some consolidation and rearrangement of the habitat categories was required in order to facilitate a more efficient presentation of the restoration alternatives and actions.

Exhibit 2.2 presents the primary restoration actions by habitat type. These habitats are described in Section 2.2. Section 2.3 discusses restoration of biological natural resources (individual species populations). Section 2.4 evaluates replacement actions (i.e., off-site or out-of-kind). Section 2.5 presents a discussion of legal and regulatory factors associated with restoration

Exhibit 2.2 Primary habitat restoration actions.

Restoration Actions	Saltmarsh	Mangrove Swamp	Freshwater Emergent Wetland	Freshwater Scrub-Shrub Wetland	Freshwater Forested Wetland	Freshwater Bogs and Fens	Intertidal Macroalgal Bed	Kelp Bed	Eelgrass (Temperate and Subarctic)	Subtropical and Tropical Seagrass Beds	Freshwater Aquatic Beds	Mollusk (Oyster) Reefs
Natural Recovery	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
Vegetation Cropping	■		■				■					
Replanting	■1	■1	■1	■1	■1		■	■1	■1	■1	■1	
Supplementary Erosion Control Structures	■											
Opening of Channels		■										
Sediment Removal and Replacement												
Off-Site Marsh Creation[2]	■1		■1	■1	■1							
Bioremediation	■					■						
Oyster Reef Reconstruction												■1
Oyster Reseeding												■1
Coral Transplants												
Sand Blasting												
Steam Cleaning		☑										
Flushing (Washing)	■	☑	☑	☑	■							
Sediment Washing												
Sediment Agitation												
Incineration												
Dredging												

Exhibit 2.2 (continued)

Restoration Actions	Coral Reef	Intertidal Rocky Shore	Intertidal Cobble-Gravel Beach	Intertidal Sand Beach	Intertidal Mud Flat	Subtidal Rocky Bottom	Subtidal Cobble-Gravel Bottom	Subtidal Sand Bottom	Subtidal Silt-Mud Bottom	Riverine Rock Shore	Riverine Sand Shore	Riverine Silt-Mud Shore	Riverine Cobble-Gravel Shore	Riverine Rock Bottom
Natural Recovery	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
Vegetation Cropping														
Replanting														
Supplementary Erosion Control Structures														
Opening of Channels														
Sediment Removal and Replacement					☑		☑	☑	☑			☑		
Off-Site Marsh Creation														
Bioremediation		☑	☑	☑	☑					☑	☑	☑	☑	
Oyster Reef Reconstruction														
Oyster Reseeding														
Coral Transplants	■1													
Sand Blasting		☑								☑				
Steam Cleaning		☑								☑				
Flushing (Washing)		☑	☑	☑						☑	☑		☑	
Sediment Washing			☑	☑							☑		☑	
Sediment Agitation			☑	☑							☑		☑	
Incineration				☑							☑			
Dredging							☑	☑	☑					

Exhibit 2.2 (continued)

Restoration Actions	Riverine Unconsolidated Bottom	Lacustrine Rock Shore	Lacustrine Cobble-Gravel Shore	Lacustrine Sand Shore	Lacustrine Silt-Mud Shore	Lacustrine Rock Bottom	Lacustrine Unconsolidated Bottom
Natural Recovery	☑	☑	☑	☑	☑	☑	☑
Vegetation Cropping							
Replanting							
Supplementary Erosion Control Structures							
Opening of Channels							
Sediment Removal and Replacement	☑				☑		☑
Off-Site Marsh Creation							
Bioremediation		☑	☑	☑	☑		
Oyster Reef Reconstruction							
Oyster Reseeding							
Coral Transplants							
Sand Blasting		☑					
Steam Cleaning		☑					
Flushing (Washing)		☑	☑	☑			
Sediment Washing			☑	☑			
Sediment Agitation	☑		☑	☑			
Incineration							
Dredging	☑				☑		☑

Natural recovery is always an alternative, the "action" as defined in this document being monitoring. In this section, reference to natural recovery as an action implies that monitoring is the only action. Monitoring should accompany all actions. Monitoring (accompanying all actions) is always technically feasible and, therefore, is not described in detail here but is discussed more fully in Chapter 3 (in discussions on each natural resource and in Section 3.2.10).

It should be noted that the distinction between "restoration" and "response" is not always clear. In general, the distinguishing features of restoration are the time period in which it occurs and the government authority overseeing the activities (see Section 1). Restoration occurs in a period of time after the initial response. In some cases, restoration actions analyzed have actually been conducted as part of response efforts, although the basic actions may be applicable to the restoration phase. For example, flushing of shorelines, vegetative cropping, or sediment agitation may be applicable to the restoration phase even though they frequently are conducted as part of an extended response phase. Other response actions are not considered appropriate to restoration activities. These include actions such as sorption and other forms of bulk oil removal.

It must be emphasized that in any restoration situation, individual site-specific conditions will greatly influence the selection of a restoration action. Thus, overall guidance, discussed in this section, should not be interpreted as a detailed step-by-step recommendation in every case.

2.2 Technical Feasibility of Primary Restoration by Habitat

This section discusses the technical feasibility of habitat restoration after an oil discharge by habitat type.

2.2.1 Estuarine and Marine Wetlands

The two major categories of estuarine and marine wetlands are saltmarshes and mangrove swamps.

2.2.1.1 Saltmarshes

Saltmarshes are typically dominated by *Spartina* spp., *Salicornia* spp., *Jaumea carnosa* (Pacific Northwest), or by *Juncus roemerianus*. While the majority of the literature focuses on *Spartina*-dominated marshes, some information exists on other types. Distinctions will be made as appropriate in the evaluations to follow.

Restoration actions developed for saltmarshes include:

- Natural Recovery;
- Replanting;
- Supplementary Erosion Control Structures;
- Sediment Removal/Replacement;
- Vegetation Cropping;
- New Saltmarsh Creation;
- Low Pressure Flushing; and
- Bioremediation.

Other actions may exist under certain situations (e.g., thermal desorption).

Replanting, supplementary erosion control structures, sediment removal (replacement) and vegetation cropping are primary restoration actions. Replanting is a key element in all active marsh restoration and will typically be a component with other actions. Erosion control structures can be coupled with replanting if it is necessary to stabilize the marsh sediment. Sediment emoval/replacement would generally be coupled with replanting. Vegetation cropping is an action that is used to remove residual oil from vegetation that may recontaminate the marsh or contaminate other natural resources. Altering the hydrology of an injured marsh might be considered in extreme cases, and would include many of the considerations under saltmarsh creation.

New saltmarsh creation refers to the development of a replacement marsh at a site different from the injured location. It typically involves hydrological changes and possibly excavation at the new site. It is frequently coupled with replanting using actions similar to those discussed under replanting. Replanting can also be used as an off-site replacement action if a suitable site is available.

Low pressure flushing is most often a response or short-term cleanup action, but it may be part of a restoration to remove residual oil. Flushing is included here because experience with discharges has shown that additional removal of oil may be required even though it is "technically" a cleanup action. Bioremediation is suggested as a potential saltmarsh restoration action but it is still being developed (see Chapter 3).

Saltmarshes are characterized by soft sediments. If marsh vegetation is destroyed, erosion of sediments can readily occur making re-establishment of the marsh difficult or impossible. Injury or alteration of the drainage channels in saltmarshes can affect proper functioning of the marsh.

Considerable injury can occur to saltmarshes as a result of improper restoration. Foot and vehicular traffic can displace sediments and work the oil more deeply into the sediments (Getter et al., 1984; Johnson and Pastorok, 1985; Seneca and Broome, 1982; American Petroleum Institute, 1991). Residual contamination may also be a problem and often complex trade-offs must be made between traffic and residual contamination. These issues are discussed in detail in Chapter 3.

2.2.1.1.1 Oil Related Literature

Restoration of a saltmarsh following an oil discharge is reported in the literature for a limited number of cases. Seneca and Broome (1982) report the results of marsh revegetation efforts in the Ile Grande marsh in Brittany after the *Amoco Cadiz* oil discharge. Krebs and Tanner (1981a) report the results of marsh restoration using a combination of sediment removal, sediment replacement, and replanting in response to an oil discharge in the Potomac River. Mearns (1991) reports on bioremediation in an oiled marsh in Galveston Bay. American Petroleum Institute (1991) evaluates potential restoration using a combination of historical data and *a priori* assumptions. Getter et al. (1984) summarizes information on the restoration of saltmarshes after potential oil discharge injury.

2.2.1.1.2 Non-oil Related Literature

Saltmarsh creation is addressed extensively by the U.S. Army Corps of Engineers including such publications as:

- Army Corps of Engineers (1978) and Woodhouse (1979) - provide design information for creating wetlands using dredged material including extensive guidelines for saltmarsh planting;

- Webb and Dodd (1978) - discuss saltmarsh planting and wave-stilling devices to control erosion in saltmarsh areas;

- Webb and Dodd (1976) - describe early saltmarsh planting projects with the objective of stabilizing marsh shorelines;

- Earhart and Garbisch (1986) - provide detailed discussion of a smooth cordgrass (*Spartina alterniflora*) planting project on a dredged material site;

- Allen et al. (1986) - discuss shore stabilization by planting smooth cordgrass (*Spartina alterniflora*) in combination with temporary breakwaters; and

- Allen et al. (1990) - discuss recent experience with planting saltmarsh species and use of temporary breakwaters to stabilize the shoreline in high wave environments.

Examples of other literature from a variety of marsh restoration efforts include:

- Josselyn and Buchholz (1982) - reports on saltmarsh creation projects in California;

- Havens and Lehman (1987) - discuss results of a saltmarsh creation project as mitigation for construction at a Navy base;

- Allen and Hull (1987) - discuss restoration of a California saltmarsh that had been degraded as a result of urban development;

- Purcell and Johnson (1991) - provide an overview of a degraded saltmarsh that was restored as part of a mitigation project;

- Josselyn et al. (1991) - describe restoration of the Bolsa Chica lowlands in southern California;

- Broome et al. (1988) - summarize their extensive experience with restoring saltmarsh vegetation; and

- National Research Council (1992) - summarizes recent findings and issues on wetland restoration.

Other directly relevant sources of information on saltmarsh creation include Garbisch (1978), Kusler et al. (1988), Josselyn et al. (1990), Broome (1990), Fauer and Gritzuk (1979), Jerome (1979), Zedler (1992), Seneca and Broome (1982), and Seneca and Broome (1992). (Note: the scientific information of these and other literature is reviewed in Chapter 3. These listed sources contain information on technical feasibility.)

2.2.1.1.3 Technical Feasibility of Restoration Actions

Exhibit 2.3 presents a summary of the state of technical feasibility for the alternatives that are discussed in the following sections. Each action should be accompanied by a monitoring program.

2.2.1.1.3.1 Natural Recovery

Monitoring is always a technically feasible action. No other action is associated with this alternative. See Chapter 3 for a discussion of recovery.

Exhibit 2.3 Overview of technical feasibility of saltmarsh restoration.

	State of Feasibility	Availability of Services Materials and Equipment	Key Constraints	Future Restoration Efforts	Legal and Administrative Factors
Natural Recovery Monitoring	Generally Feasible	Generally available	Little constraint	Replanting or erosion control may be necessary	Coordination of monitoring activities
Replanting	Action has generally been well developed	Specialist restoration firms exist in many areas Experienced labor may be limited Lead time required for nursery plants	Degradation of oil in sediment Tide hampers work Degree of fetch Seeding confined to protected sites Nursery availability for target species may be limited Donor sites for natural propagules	Replanting due to transplant mortality Fertilization	Some states may require permits for gathering propagules
Erosion Control Structures	Generally feasible but varies by site-conditions	Generally available	Large structures require equipment access	Repair Removal	Permits from Army Corps of Engineers and many states

Exhibit 2.3 (continued)

	State of Feasibility	Availability of Services and Materials	Key Constraints	Future Restoration Efforts	Legal and Administrative Factors
Sediment Removal/ Replacement	Feasible in only limited circumstances	Readily available in most regions	Possibility of further injury Equipment access	Method may increase injury resulting in extensive additional restoration	Permits from Army Corps of Engineers and many states may be scrutinized
Vegetation Cropping	Generally feasible	Readily available	Possibility of further injury	Collateral injury may result in additional restoration	No formal requirements
New Saltmarsh Creation	Generally feasible, but may require using off-site location	Variable, since projects may range from simple services to massive construction projects	Acquisition of site Establishment of hydraulic regime Availability of suitable substrate Controlling contaminants Pest species	Most viable projects have extensive programs of evaluation and mid-course corrections	Army Corps of Engineers and state agencies have time consuming permit procedures Negotiation for site acquisition
Low Pressure Flushing	Feasible in limited circumstances	Available from oil spill response contractors	Access to marsh interior Possibility of further injury	Additional restoration due to injury caused by the action	No formal requirements
Bioremediation	Action is currently being developed	Services are available from specialists	Few people have strong bioremediation expertise in estuarine and marine systems Possible eutrophication effects	None expected	Permits required

2.2.1.1.3.2 Replanting

Many experts conclude that saltmarsh planting and associated restoration has reached the stage of development where it can be considered a fully feasible method. These experts include Woodhouse (1979), U.S. Army Corps of Engineers (1978), Garbisch (1978), Earhart and Garbisch (1986), Broome et al. (1988), Getter et al. (1984), Seneca and Broome (1992), Josselyn and Buchholz (1982), National Research Council (1992), and others. Zedler (1992) cautions that feasibility is limited to the actual establishment of vegetation that has similar characteristics to control marshes and that full functional equivalence to natural saltmarshes has not been achieved. (See Section 3.2.1 for discussion of effectiveness and success.)

Work conducted by the U.S. Army Corps of Engineers on the large-scale planting of saltmarsh species, which began in the early 1970s, has lead to highly developed replanting actions. In the last decade the proliferation of wetland restoration projects as mitigation for construction has further developed the state of the art. However, there have been few studies that have evaluated the success of these actions, except on the vegetation. (See Chapter 3.2.1.)

Replanting is a prime component of almost all active saltmarsh restoration efforts. The principal methods include:

- Seeding using seed harvested and threshed from a local site;
- Seeding using seed purchased from a commercial supplier;
- Transplanting with sprigs or plugs dug from a nearby saltmarsh site; and
- Planting greenhouse-grown seedlings.

Propagule is a general term for any of various structures used to propogate a plant including seed, seedlings, sprigs, and plugs. Seedlings are small nursery grown plants grown from seed for transplanting. Sprigs are plant stalks with attached roots and rhizome fragments, but with little substrate material. Plugs are plant stalks with a core of intact substrate material, roots and rhizomes.

The planting task can be divided into acquisition of the propagule, and the actual insertion of the propagule into the substrate. Acquiring the propagule from a commercial supplier eliminates the need for including the digging of sprigs or plugs or threshing and harvesting the seed in the scope of the restoration project. However, locally-acquired propagules can be better adapted to the restoration site and may have a higher confidence rate of plant establishment.

Planting can be accomplished using hand methods, semi-mechanized methods using a powered auger, and mechanized methods employing a small agricultural tractor. A limiting factor in the use of the tractor method is the bearing ability of the saltmarsh sediments, accessibility into the marsh, and the size of the project. Mechanized methods may also kill marsh biota left alive through trampling and disruption of root systems (see Section 3.2.1).

Fertilizers are frequently valuable in helping with plant establishment on sandy soils. In other types of soil, they are useful on occasion (Woodhouse, 1979). A slow-release fertilizer can be inserted along with the plug or sprig which will enhance early establishment. Conventional broadcast fertilizers can be applied later during the first year of growth. However, fertilization may interfere with development of the infaunal community and add unnecessary contaminants into the system (see Section 3.2.1).

Smooth cordgrass (*Spartina alterniflora*) is the dominant vegetation in the regularly flooded intertidal saltmarshes on the east and Gulf of Mexico coasts of the United States. Plants that dominate at the higher marsh elevations are saltmeadow cordgrass (*Spartina patens*), saltgrass (*Distichlis spicata*), and black needlerush (*Juncus roemerianus*). Pacific cordgrass (*Spartina foliosa*) is a dominant saltmarsh species in California. Tidal marshes in the Pacific Northwest are typified by such species as, *Salicornia virginica* and *Jaumea carnosa.* Attention must be paid to ensuring that only species indigenous to a specific geographic area are planted. For instance, *Spartina alterniflora* is considered a non-native invasive species on the west coast. *Spartina alterniflora*, *S. anglica*, and *S. patens* are included on the Washington State Noxious Weed List as plant species considered detrimental to natural resources of the state.

Availability of Services, Materials, and Equipment

A number of commercial firms engage in wetland restoration. The growth of such firms was spurred by wetland mitigation projects to offset wetlands lost for construction projects. However, such firms are not widely distributed across the United States. Typically, firms are located in the major areas of the country with broad distribution of *Spartina*-dominated saltmarsh environments. Therefore, restoration activities in isolated areas or where other species dominate may involve considerable travel by specialist restoration firms.

Wetland restoration firms tend to be small specialist operations. A very large restoration project could overwhelm the capabilities of local establishments. Some of the past marsh restoration activities have involved the use of general labor, relatively inexperienced in saltmarsh restoration. Success of the restoration effort is dependent upon experienced supervision by a person knowledgeable in saltmarsh restoration. Some commercial nurseries are beginning to specialize in wetland plant species. However, several months lead time may be required to prepare transplant material. In planning for saltmarsh planting, it is important to coordinate the acquisition of transplant material well in advance of needs.

Constraints

There are a number of operational constraints which may complicate replanting. For example:

- Planting activities must not begin until the oil in the sediment has degraded sufficiently to insure success (see Chapter 3);

- Tides in the saltmarsh environment affect the accessibility to sediments for marsh restoration. Harvesting and planting activities in many locations are confined to a five-hour period per tide, necessitating careful coordination to achieve efficient utilization of personnel and equipment (Woodhouse, 1979);

- Saltmarshes can be established on a wide variety of soils including sand, silt, clay, and peat. Planting is easiest in sand and most difficult in peat; plant growth is usually most effective in silt and clay (Woodhouse, 1979; Broome et al., 1988);

- While seeding is the least expensive method of propagation of saltmarsh species (Section 4.2.1.1.3.2), the use of this action must be confined to protected sites. Seeding is also restricted to the higher elevation areas of the marsh and is limited by seasonality;

- Because of the delicate nature of saltmarsh habitats, foot and vehicular activity in the marsh must be carefully monitored in order to minimize injury. This may be a particular concern if the project is employing relatively inexperienced labor;

- The use of fertilizer may cause concern over eutrophication and encouragement of weed growth; and

- Grazing by herbivores may hinder establishment of planted material.

Future Restoration Actions

Information presented in Broome et al. (1988) suggests that typically about 20 percent of a *Spartina* marsh requires replanting due to transplant mortality. Additional maintenance activities during the first year of marsh establishment include a broadcast application of conventional fertilizer.

2.2.1.1.3.3 Supplementary Erosion Control Structures

Some form of erosion control structure may be necessary in certain instances, such as when the substrate or vegetation is injured to a degree that erosion is a threat. Exposed marshes, where there is a long fetch allowing waves to build, are most vulnerable. Typical erosion control structures suitable for use in saltmarsh restoration projects include:

- Hand-placed slat-type sand fences;
- Small hand-placed sand bags;
- Scrap tire erosion control barriers; and
- Cloth mesh fence.

While large heavy duty sand bags placed with heavy equipment may offer more protection in very exposed situations, their cost is high and the site must have suitable access. Many previously-placed scrap tire erosion control barriers are now being dismantled and their present use may be problematic. Shell cultch can also be used as an erosion control approach (see Section 2.2.4).

<u>Availability of Services, Materials, and Equipment</u>

Woodhouse (1979) reports that slat-type sand fence is available commercially as an erosion control structure. Small sandbags may also be used and installed with hand labor. These materials present no unusual problems in terms of acquisition. The availability of scrap tires varies locally by geographic area.

Larger, more heavily constructed sand bag structures are considerably more expensive and require access routes for heavy equipment (U.S. Army Corps of Engineers, 1978).

<u>Constraints</u>

The large, heavy sand bag erosion control structures are generally limited by accessibility requirements for construction equipment. Such equipment is necessary for filling and placing the structures.

Future Restoration Actions

Periodic repair may be required to maintain effectiveness of the temporary erosion control structures. The devices will have to be removed after the vegetation has established itself sufficiently to stabilize the sediments.

2.2.1.1.3.4 Sediment Removal / Replacement

Krebs and Tanner (1981a) report on the use of sediment removal and replacement as a marsh restoration action. Sediment is removed using excavation equipment such as track-mounted power bucket shovels. When employed, this action would be coupled with replanting as discussed in Section 2.2.1.1.3.2. The primary reason for implementing this is to remove substrate heavily saturated with oil. (See discussion in Chapter 3.)

Availability of Services, Materials, and Equipment

Sediment removal involves the use of readily available construction equipment and services. Firms having the necessary equipment and personnel are geographically far apart. However, because of the significant care that is required to mitigate injury to the marsh, the sediment removal effort should be closely supervised by persons experienced in marsh restoration to prevent unnecessary damage to plants and disruption of the marsh substrate. A "safe" means of disposal is required for the oil-saturated soil. Unfortunately, many locations in the country are located at considerable distance from disposal sites.

Constraints

A major constraint with this action is access to the marsh area by construction equipment. Sediment removal may not be feasible if the sediments consist of fine mud (Getter et al., 1984). This could prevent the conventional excavation equipment from operating in the marsh area. Specialized or "exotic" actions may be available in soft sediments. However, their use in restoration has not been documented.

A related issue is the significant risk of injury to the marsh by equipment and traffic. This action may only be applicable to narrow fringing marshes due to limited access.

Sediment removal without backfilling with clean material lowers the elevation of the substrate and may alter the hydrologic characteristics of the marsh. Thus, sediment removal is only applicable if the substrate slope is relatively steep (i.e., greater than three degrees), otherwise excessive amounts of marsh area could be lost (Krebs and Tanner, 1981a). Also, sediment removal without backfilling may increase the potential for erosion. If backfilling of the stripped sediment is applied, a source of clean fill material must be found. This may be a difficult task at certain restoration sites. Grading of the backfilled area will be required to attain the proper slope and elevation for marsh development.

2.2.1.1.3.5 Vegetation Cropping

Vegetation cropping was performed in a number of cases after oil discharges in saltmarshes. Examples include (Johnson and Pastorok, 1985):

- The *Esso Bayway* discharge in 1979 near Port Neches, Texas;
- The barge *STC-101* discharge in 1976 in lower Chesapeake Bay;
- The *Amoco Cadiz* discharge in 1978 on the coast of France;
- A pipeline discharge in 1974 in Texas; and
- A tank farm discharge in 1976 in the Hackensack River.

While vegetation cropping in these cases was part of the later stages of cleanup activity, the action may be applicable to the restoration phase if heavily oiled marsh vegetation persists. The objective of this action is to remove residual oil that could continue to contaminate the marsh or recontaminate surrounding habitats and biota (such as wildlife).

The general procedure for vegetative cropping consists of manual cutting of the top portions of marsh vegetation using hand tools such as shears, power brush or weed cutters, scythes, or similar devices. After the vegetation is cut, the debris is collected and put into plastic bags for disposal. The work is labor intensive.

This procedure can be injurious to plants. Vegetation cropping typically involves a great deal of pedestrian traffic in the marsh area. This heavy foot traffic has the potential to cause additional injury to the marsh due to trampling vegetation, pushing residual oil deeper into the sediments, disrupting the contour of the marsh substrate, and causing the potential for erosion. In some cases it is feasible to perform the cutting from small boats in the marsh channels. Care must be exercised in the cutting operation to prevent excessive cutting, which may injure the plant root structure (Owens et al., 1992).

The widespread historical usage of this procedure demonstrates the technical feasibility of performing vegetation cropping. This procedure is performed in conjunction with numerous oil discharges in marshes and knowledge of the action is widespread among oil discharge response companies and cooperatives.

Availability of Services, Materials, and Equipment

The method uses general hand labor and small off-the-shelf hand tools. These services and equipment are readily available around the country.

Constraints

This action may have serious problems associated with collateral injury to the marsh. Very soft sediments make access to the marsh difficult on foot and may significantly increase the potential for erosion in the marsh. Erosion can cause extensive injury to the marsh, including loss of suitable substrate and altering of the hydrologic characteristics.

Future Restoration Actions

If this procedure causes additional injury to the marsh, the extent of future restoration actions would increase. Additional injury to the marsh could include further destruction of plants, injury from erosion, and deeper penetration of oil into sediments.

2.2.1.1.3.6 New Saltmarsh Creation

New saltmarsh creation constitutes an off-site replacement type of restoration action. In general, of all wetland types, saltmarsh restoration has been most often attempted. This is attributable to the depth of experience in restoring this wetland type, the ease with which proper elevations can be established (using tide records), and the relatively few plant species that occur in saltmarshes (National Research Council, 1992).

Possible restoration sites could consist of:

- A saltmarsh that was previously degraded due to diking, draining, canals, elevation changes, poor water quality, previous flood control projects, etc.;
- Establishment of a new wetland on a site where disposed dredge spoil has been deposited; and
- Excavation of an upland site.

As early as the mid-1970's, efforts were established to restore injured saltmarshes. One of the largest programs was conducted by the U.S. Army Corps of Engineers. Many state regulations now require mitigation efforts to offset loss of wetlands due to construction projects.

The general actions for creating new saltmarsh involve the following tasks (King, 1991):

- Establish or control the proper hydrology. This may involve:
  - Removing or breaching dikes or levees;
  - Creating tidal channels;
  - Diverting waterflow to or away from site; and
  - Regulating the hydraulic regime, using control structures if necessary;

- Modify substrate, if necessary
  - Excavate to correct elevation and contour
  - Control contaminants
  - Achieve proper soil conditions through fertilization, addition of organic matter, etc.

- Plant vegetation (similar to replanting)

- Monitor progress and make mid-course corrections
  - Monitor marsh productivity;
  - Monitor marsh function;
  - Modify hydraulic regime;
  - Replant; and
  - Control pest species.

Any saltmarsh creation project will involve various combinations of activities that will be highly site-specific. The actual scope of restoration activities will vary significantly depending upon the characteristics of a particular project. Some projects may involve simple breaching of a dike (if the land has not subsided), followed by natural propagation of plants or basic replanting of saltmarsh species. Others may involve extensive re-contouring of site topography using construction equipment. Establishment of the proper hydrological regime may require a complex set of control structures or pumps.

For marshes created on dredge spoil, the concept is similar to marshes created on degraded areas. However, establishment of the substrate at the proper elevation is done by depositing dredge spoil material from U.S. Army Corps of Engineers waterway dredging projects. This frequently requires dewatering and mechanical grading of the spoil material. These types of projects were originally created to find a method for disposal of the dredged material.

Availability of Services, Materials, and Equipment

The requirements for services, materials, and equipment will vary greatly depending on the particular scope of a project. Simple projects will have service requirements similar to those for replanting. For projects with modifications to the topography and hydrology, extensive construction services will be required. This may involve both land-based excavation equipment as well as water-based heavy construction equipment.

For projects established on dredge spoil, the substrate is typically established using water-based barge and dredge equipment. Since these projects are undertaken in conjunction with normal dredging activities, the basic equipment would be available in conjunction with the dredging activities. Grading may require excavation equipment.

Constraints

A significant constraint to the creation of a new saltmarsh is the location of a suitable site. The availability of such sites will vary greatly by location around the country. Another constraint may relate to the establishment of the proper hydrologic regime on the chosen site. If natural flushing does not function effectively at a particular site, a complex series of channels and control structures may be necessary. Some potential sites may be constrained by previous contamination of the substrate. Many degraded wetlands in urban areas are polluted with long-term loadings of toxicants. During the establishment period of the marsh, pest species may invade the site. (This is more problematic on the U.S. west coast than the east or Gulf of Mexico coasts.) Invasive plants may require time-consuming weed removal. Animal pests may require fencing of the area. Insect pests may be problematic and difficult to control.

Future Restoration Actions

This will vary greatly depending on the characteristics of a particular project. To ensure a reasonable chance of success, an extensive program of monitoring and mid-course corrections is required.

2.2.1.1.3.7 Low Pressure Flushing

Low pressure flushing is a technically feasible action in limited circumstances for removing residual oil in marshes. It may not be possible to remove heavily weathered oil without damaging the plant structure and substrate. Typically, engine driven pumps are used to pump water through hoses to flush the oil from contaminated vegetation into marsh channels for subsequent containment and recovery with booms and sorbents. While flushing can be performed from land, it is generally preferred that it be performed from small boats to prevent trampling of vegetation (Johnson and Pastorok, 1985).

Availability of Services, Materials, and Equipment

Equipment and personnel to perform this action are typically available from oil discharge response contractors.

Constraints

Access to the interior of a marsh can be a significant constraint to the use of this action.

Future Restoration Actions

This action may cause further damage to marsh plants and erosion of substrate, thus increasing the need for future restoration actions.

2.2.1.1.3.8 Bioremediation

Bioremediation is a potential technically feasible action for restoration in a marsh. Mearns (1991) reported on the use of bioremediation in an oiled marsh in Galveston Bay. See Section 2.2.6.1.3.5. for a general discussion of bioremediation.

2.2.1.2 Mangrove Swamps

Low-wave energy ecosystems such as mangrove swamps are sites where oil commonly accumulates after a discharge. Mangrove habitats are comprised of complex intertwining root formations that can make the habitats inaccessible, thus hindering the effectiveness of oil removal activities. Restoration actions identified in the literature for affected mangrove habitats include:

- Natural Recovery;
- Replanting;
- Construction of Channels;
- Low Pressure Flushing; and
- Bioremediation.

Replanting can be used as an off-site replacement action, if a suitable site is available. Bioremediation is an action still under development (Scherrer and Mille, 1989).

2.2.1.2.1 Oil Related Literature

Documented restoration projects performed in oil-injured mangrove habitats are identified in Lewis (1981), Lewis (1979), and Mangrove Systems, Inc. (1980). Other literature identifies oil-related impact to mangroves and the necessary activities for restoration (Gilfillan et al., 1981; Getter et al., 1984; Evans, 1985; Teas et al., 1989a,b; and Ballou and Lewis, 1989; Cintron-Molero, 1992).

2.2.1.2.2 Non-oil Related Literature

Mangrove habitats have long undergone stresses from both natural occurrences and man-induced impacts. Injury from natural occurrences includes the impact of hurricanes, natural erosion processes, and tree loss from lightning strikes. Man-induced impacts include stresses related to coastal development and operations such as dredge-and-fill practices.

Literature documenting non-oil related restoration projects involving mangroves include Teas (1977), Goforth and Thomas (1979), and Sosnow (1986). Teas (1977) discusses replanting actions. Goforth and Thomas (1979) detail mangrove restoration for the stabilization of eroding shorelines and replanting activities with the use of small trees. In addition, Sosnow (1986) describes mangrove restoration using seedling plantings in a restoration project performed to mitigate the impacts caused by port dredging activities. Cintron-Molero (1992) recommends natural recovery except in those areas that do not have a ready source of propagules. While these were the primary sources used, there is also a broad body of literature involving mangrove protection and planting, since this was a major issue in South Florida for two decades.

2.2.1.2.3 Technical Feasibility of Restoration Actions

Exhibit 2.4 presents a summary of the state of technical feasibility for each restoration action. Each action includes a monitoring program.

2.2.1.2.3.1 Natural Recovery

Monitoring of natural recovery is always technically feasible. See Chapter 3 for a discussion of monitoring and recovery mangrove swamps.

2.2.1.2.3.2 Replanting

Technically feasible methods of mangrove replanting include the use of, propagules, seedlings or young mangrove trees.

Exhibit 2.4 Overview of technical feasibility of mangrove restoration.

	State of Feasibility	**Availability of Services and Materials**	**Key Constraints**	**Future Restoration Efforts**	**Legal and Administrative Factors**
Natural Recovery	Generally feasible	Generally available	Little constraint	Replanting may be necessary	Coordination of monitoring activities
Replanting	Demonstrated as feasible under proper conditions	Seasonal availability of propagules Donor sites for trees are limited Specialists exist in many areas	Site elevation Tidal influence Substrate Herbivory Plant quality Residual oil contamination in sediment	Replanting due to transplant mortality	Permits
Construction of Channels	Suggested in literature, but viability not demonstrated	Equipment generally available	Site access for equipment Activities may cause further injury to habitat	Method may cause additional injury requiring further restoration	Dredging permits

Exhibit 2.4 (continued)

	State of Feasibility	Availability of Services and Materials	Key Constraints	Future Restoration Efforts	Legal and Administrative Factors
Low Pressure Flushing	Feasible in limited circumstances	Available from oil spill cleanup contractors	Access to marsh interior Excessive soil contamination	Additional restoration due to damage	No formal requirements
Bioremediation	Action is currently being developed	Services are available from specialists	Few people have strong bioremediation expertise in estuarine and marine systems Work crew access needed Possible eutrophication effects	None expected	Permits required

2.2.1.2.3.2.1 Propagule and Seedling Plantings

In this discussion, propagules refer to the seeds or sprouted seeds that are collected directly from mature mangrove trees, or gathered shortly after dropping from trees before exhibiting any additional growth or root formation. Propagules used for mangrove restoration are generally planted or directly inserted into the substrate at a depth of a few inches. Mangrove seedlings are propagules that have germinated and show additional signs of growth such as root development. Seedlings are commonly grown in nursery conditions for a short growing period (3 to 18 months) before they are used for planting material at restoration sites.

The use of both propagules and seedlings is technically feasible as demonstrated in past mangrove restoration projects (Cairns and Buikema, 1984; Getter et al., 1984; Lewis, 1979; Lewis, 1990; Teas, 1977; Teas, 1981; and Teas et al., 1989a,b). For example, just a few years after mangrove propagules were planted in an injured habitat the height and size of canopy developed by the propagules was comparable to that of transplanted, 1-meter high (3 year old) trees (Lewis, 1991). The survival rate of transplanted propagules or seedlings can range from 0% to 100% depending on various characteristics including the action of planting, the type of plant material used, and the planting site.

Propagules are typically the more practical planting method for red mangroves for several reasons. First, propagules are more cost-effective than nursery-raised seedlings. Second, propagules adapt more readily to a habitat because they are not influenced by nursery conditions in which seedlings are raised, offering easier acclimatization to a restoration site. Third, propagules are not as susceptible to injury from wind and other environmental stresses that may blow over top-heavy potted seedlings (Crewz and Lewis, 1991). When planted at the proper elevation in sheltered areas, red mangrove propagules may survive at least as well as older, nursery-grown seedlings (Goforth and Thomas, 1979).

For black and white mangrove species, direct planting of propagules may be impractical, because the propagule must remain on a damp substrate for several days to germinate and anchor properly. Due to the high probability that these propagules may be removed by tides or other influences, planting of black and white mangroves is generally performed using seedlings raised in a nursery environment.

<u>Availability of Services, Materials, and Equipment</u>

Material for propagule plantings is limited to the availability of fresh seeds from mangrove trees. The timing of propagule "drops" is important for restoration planning due to the seasonal availability of this planting material. Red mangrove propagules tend to be available only during a limited period between the summer and fall and cannot be stored for long periods of time. The availability of mangrove propagules in the quantity needed for a planting project typically limits the window of planting opportunity from mid-August to mid-October when the peak fruiting period ends (Getter et al., 1984; Lewis, 1990).

Mangrove seedlings used for replanting injured mangroves are commonly gathered from natural stocks in nearby mangrove habitats or purchased from nursery suppliers. Commercial suppliers of plant material generally have certain species of mangrove seedlings available year-round. If large quantities of certain types of seedlings are needed, longer lead times may be required for contracting nursery plant production.

Mangrove propagules and seedlings are commonly planted by hand using readily available equipment such as boring and digging tools.

Mangrove restoration requires specialized technical expertise to oversee projects. Technical expertise is generally available throughout the regions mangroves inhabit, but may be limited to academic and government scientists and a small number of specialist restoration companies. Most efforts at mangrove restoration noted in the literature where planting actions were employed represented a collaboration of individual expertise that was readily accessed.

Constraints

The following identifies several important factors for planning a mangrove restoration site using propagules and seedlings for planting material.

- Planting Elevation and Slope. For all mangrove restoration sites, the correct intertidal zone elevation must be determined before planting, generally located between mean sea level and mean high water. Elevations depend on the tidal range and should be determined based on the species type to be planted. A survey of existing mangroves at the closest location to the planting is an easy method of determining the correct elevation to plant;

- Tidal Influence/Wave Action. Mangrove plantings are not as viable when performed at restoration sites with high wave energy and tidal influence. The increased wave action can wash the propagules away or disrupt the rooted seedling A review of past plantings in high wave action areas concluded that all attempted plantings, even those at sites with some sort of wave barrier, were not technically feasible due to environmental conditions (Getter et al., 1984). Therefore, a restoration planting site should be one with little or no wave action against the shore to dislodge plantings. Other constraints to performing mangrove planting include stressful environmental conditions such as extremely hot or cold weather, high winds, and low rainfall periods;

- Substrate. There is wide geographic variability in the types of substrates in which mangroves grow. Plantings should be performed in stable substrate, composed of materials such as marl muds and peat mixes. Soil that consists of rock or clay layers may be unacceptable for planting unless it is substantially modified. Sand, clay, or marl substrates may need organic matter added to promote drainage and to support plant and animal colonization, survival, and growth (Crewz and Lewis, 1991);

- Plant Quality. Propagules and seedlings used for planting should be protected from sun and desiccation during transport to the restoration site. For material which is produced by a nursery, the plants should be raised under nursery conditions similar to the conditions at the planting site. Plants destined for saline sites should be raised under a constant salinity regime, not just acclimatized a few weeks prior to planting. When rapid coverage of a site is needed, one- to two-year-old seedlings should be used rather than propagules (Crewz and Lewis, 1991); and

- Sediment Stability. In less stable restoration sites, properly staked, rooted seedlings may be better to use than propagules. Shifting sediments and water movements can easily uproot propagules, while rooted seedlings have a greater chance of survival. In addition, rooted seedlings can also provide greater plant coverage over the short term than propagules and exhibit earlier prop root development for stabilization.

Suitable habitat and environmental conditions are required for maximum growth, survival, and voluntary recruitment of planting material. Primary causes of loss of transplanted propagules and seedlings include:

- Physical removal due to erosion, accumulation of foreign plant material, or floating debris;

- Attacks from organisms such as crabs that eat the seeds, and, in some areas, removal of plants by animals such as rabbits and monkeys;

- Planting at too high an elevation;

- Mortality due to residual oil or other contamination (Getter et al., 1984); and

- Mortality due to natural causes.

In an oil discharge site, the technical feasibility of restoration may be hindered due to residual oil in the sediment causing plant mortality from chronic oil contamination. Some plant material may experience high rates of mortality and some can survive but may develop at a slower growth rate. Additional injury may be imposed on a habitat by excessive human and mechanical intrusion as a result of restoration activity. The use of heavy equipment and steady foot traffic in affected marsh areas could kill existing plant material and prolong soil contamination.

Future Restoration Actions

Additional replanting may be required due to transplant mortality.

2.2.1.2.3.2.2 Young Trees

Mangrove restoration using small mangrove trees as planting material typically involves transplanting nursery-raised trees (approximately 3-5 years old) or trees taken from a nearby donor mangrove habitat. Planting of small mangrove trees from nursery stock provides a potential means of obtaining more rapid growth and substrate stabilization than could be expected from planting propagules or seedlings (Teas, 1977). Mangrove trees were used for restoration projects in both sheltered and eroding or high wave energy areas (Getter et al., 1984; Goforth and Thomas, 1979).

A review of several studies where young mangrove trees were used as transplant material notes that the technical feasibility of using this method has mixed results (Lewis, 1990). Each planting site where trees are used either from donor sites or nursery raised material is unique and transplant viability is primarily the result of actual site characteristics and the type and species of plant material. Survival of transplants using small trees were documented in one report to range from 16% to 100% based on a review of past planting projects (Getter et al., 1984). Factors contributing to transplant mortality included unstable substrate and stress from high wave energy shorelines. Another study indicated that mangrove transplants of 2-3 year old trees had a survival of 98% in 23 months in exposed or high energy areas (Goforth and Thomas, 1980).

Availability of Services, Materials, and Equipment

Small mangrove trees are available year-round from commercial nursery suppliers, although they are generally obtained at a high cost. The availability of trees from donor mangrove habitats is limited due to a lack of available mangroves and increasing concerns for the mortality of mangroves moved long distances or from one region to another. It is recommended by mangrove specialists that plant materials should originate from areas as close as possible to the restoration site (Crewz and Lewis, 1991; Lewis, 1990). Reasons for restrictions on plant material imported from foreign mangrove populations include concerns about transporting "exotic" organisms or diseases between regions, and concerns about diluting the locally adapted genetic stock of mangrove species. Current polices for mangrove site creation and restoration are beginning to restrict the use of plant material from different vicinities.

Required technical expertise on mangrove restoration is available as discussed in Section 2.2.1.2.3.2.1.

Constraints

As described above for propagule and seedling plantings, restoration site conditions are critical to the success of mangrove transplants. Further, the considerations regarding planting elevation and slope, tidal influence and wave action, and substrate quality are equally significant for mangrove trees. For transplanting small trees into a restoration site, the use of plant material from a different ecological zone can affect the reliability of transplants. The tolerance of plant material to restoration site conditions can vary by type of species and care must be taken to properly acclimatize the plant material to the environmental conditions of the transplant site. Plant material that is provided from donor mangrove habitats should come from stock which is native to the region where the restoration site is located. Transport methods and handling of mangrove trees can also affect the viability of the planting effort. Plants should be kept cool, moist, and out of the direct sunlight during transport. In addition, for donor sites, the following guidelines should be met during the transplant procedure:

- Top and side branches should be pruned to two-thirds their original length;
- Trees should be removed with a root ball diameter about half the original tree height;
- The root ball should be watered and stamped down while replacing soil to provide sealing between the root ball and the sides of the hole;
- Trees should be replanted at approximately the same level in the ground and at approximately the same tidal elevation as in the original habitat; and
- Trees should never be planted in unstable substrate.

For all mangrove species, the optimum time period to install mangrove trees is from April to mid-June (Lewis, 1990). Therefore, restoration sites that require construction must be completed prior to the planting window.

Future Restoration Actions

Replanting may be required due to transplant mortality. However, if mangrove trees experienced a high mortality rate after being transplanted and no natural colonization or signs of recovery have occurred, the restoration site may be unsuitable.

2.2.1.2.3.3 Construction of Channels

The construction of channels to increase the level of flushing through a contaminated mangrove habitat was suggested as a restoration action (Ballou and Lewis, 1989). Creating channels may induce flushing (Ballou and Lewis, 1989) and greater habitat circulation (Evans, 1985). However, the literature does not identify specific restoration projects where this action has been demonstrated as successful (see Section 3.2.1).

Availability of Services, Materials, and Equipment

The resources needed to perform construction of channels in an injured mangrove community include materials, equipment, and personnel to perform the desired degree of excavation. This is typical construction equipment that is readily available. Specialized technical expertise to oversee projects is required and is available as discussed in Section 2.2.1.2.3.2.1.

Constraints

Equipment access for the excavation of channels has the potential to be a difficult task depending on channel location. According to Ballou and Lewis (1989), the optimal location for a channel depends on a number of site-specific considerations such as salinity, water levels, and hydrological conditions. Actual siting involves making a site-specific assessment.

A concern regarding the construction of channels as a restoration action is the potential for collateral injury imposed on the mangrove community as a result of this activity. Implementation of channel construction can alter the natural hydrologic conditions of the mangrove habitat (see Chapter 3).

Future Restoration Actions

Future restoration actions may be required due to damage from construction actions.

2.2.1.2.3.4 Low Pressure Flushing

See Section 2.2.1.1.3.7.

2.2.1.2.3.5 Bioremediation

Bioremediation is a potentially technically feasible restoration action in mangrove swamps. Scherrer and Mille (1989) document biodegradation of crude oil in experimentally oiled mangrove soil. See Section 2.2.6.1.3.5 for a general discussion of bioremediation.

2.2.2 Freshwater Wetlands

Restoration of freshwater wetlands, including riverine and palustrine, is similar in concept to the restoration of saltmarshes. However, freshwater wetlands possess some unique characteristics. Exhibit 2.5 summarizes the state of technical feasibility for freshwater wetlands.

2.2.2.1 Emergent Wetlands

Restoration alternatives developed for freshwater emergent wetlands include the following:

- Natural Recovery;
- Replanting;
- Soil Removal/Replacement;
- Vegetative cropping;
- New Wetland Creation;
- Low Pressure Flushing; and
- Bioremediation.

2.2.2.1.1 Oil Related Literature

While there is not an abundance of literature regarding mitigating impacts of oil discharges on freshwater marshes, the following studies document restoration activities following oil discharges:

- Foley and Tresidder (1977) reported on vegetation cropping in response to the NEPCO 140 oil discharge in the St Lawrence River in 1976; and
- Pimentell (1985) reported on restoration including vegetation cropping, sediment removal, and creation of marsh areas adjacent to Little Panoche Creek in Fresno County, California, after a crude oil discharge in 1983.

Exhibit 2.5 Overview of technical feasibility of freshwater marsh restoration.

Restoration Actions	Emergent Wetland	Scrub/Shrub and Forested Wetland	State of Feasibility	Availability of Services and Materials	Key Constraints	Future Restoration Efforts	Legal and Administrative Factors
Natural Recovery	Natural Recovery	Natural Recovery	Generally Feasible	Generally available	Little constraint	Replanting may be necessary	Coordination of monitoring activities
Replanting	Replanting	Replanting	Action has generally been developed	Specialist restoration firms exist in many areas Experienced labor may be limited Lead time required for nursery plants	Degradation of oil in sediment Donor sites for natural propagules Nursery availability for target species may be limited Appropriate elevation and slope Equipment access for tree planting	Replanting due to transplant mortality Elimination of pest species	Some states may require permits for gathering propagules
Soil Removal/ Replacement	Soil Removal/ Replacement		Feasible in only limited circumstances	Readily available	Possibility of further injury Equipment access	Method may increase injury resulting in extensive additional restoration	Permits

Exhibit 2.5 (continued)

Vegetation Cropping	Vegetation Cropping		Generally feasible	Readily available	Possibility of further injury	Collateral injury may result in additional restoration	No formal requirements
New Wetland Creation	New Wetland Creation	Soil Removal/ Replacement	Action has been developed	Variable, since projects may range from simple services to massive construction projects	Acquisition of site Establishment of hydraulic regime Controlling contaminants Pest species	Most viable projects have extensive programs of evaluation and mid-course correction	Permit procedures Negotiation for site acquisition
Low Pressure Flushing	Low Pressure Flushing	Vegetation Cropping	Feasible in limited circumstances	Available from oil spill cleanup contractors	Access to marsh interior	Additional restoration due to damage	No formal requirements
Bioremediation	Bioremedia-tion	New Wetland Creation	Action is currently being developed	Services and equipment generally available	Few people have strong bioremediation expertise in estuarine and marine systems Work crew access needed Possible eutrophication effects	None expected	Permits required

2.2.2.1.2 Non-oil Related Literature

No literature was identified that discussed restoration following discharges of hazardous materials in emergent freshwater wetlands. The following reports discuss restoration in regard to creation of wetlands or the restoration of wetlands previously drained for agriculture:

- Crabtree et al. (1990) describe cases across the country where freshwater marshes were constructed, replanted, and evaluated;

- Bacchus (1989), Clewell (1981), and Willard and Reed (1988) discuss the use of muck/mulch as a seed bank;

- Lee et al. (1976) address various uses of vegetation in conjunction with disposing dredged materials; and

- Piehl (1986), Rondeau (1986), and McCabe and Phillips (1986) address the reclamation of wetlands previously drained for agriculture but being returned to wetland status under a conservation plan. Should these areas be available for wetlands creation, cost-effective creation of new wetlands may be possible.

2.2.2.1.3 Technical Feasibility of Restoration Actions

The following paragraphs discuss the technical feasibility of emergent freshwater wetland restorations actions. Each action should include a monitoring program.

2.2.2.1.3.1 Natural Recovery

Natural recovery monitoring is technically feasible in all cases. See Chapter 3 for an evaluation of recovery with no action.

2.2.2.1.3.2 Replanting

Replanting was used effectively in numerous cases of restoration of emergent freshwater wetlands (typically in response to development permits). Crabtree et al. (1990) describe cases in a number of states where freshwater marshes were constructed, replanted, and evaluated. The widespread historical use of this action demonstrates the overall technical feasibility of replanting efforts. (However, see Section 3.2.2 for discussion of effectiveness and success).

The primary concern from a technical feasibility perspective is the type of species planted in a particular area and availability of the species selected. Lee et al. (1976) reported that the plant species commercially available include *Scirpus robustus* (bulrush), and *Typha latifolia* (cattail). While, the technical feasibility of replanting saltmarsh species is discussed in many literature sources, less has been published on freshwater species. However, examples of the feasibility for various plants exist. Crabtree et al. (1990) describes the following cases:

Location	**Method of Replanting**	**Species Replanted**
Lake Hunter, Florida	Mulching	Pickerelweed, Maidencane, Arrowhead, and Spikerush
Patuxent River, Maryland	Plants and rhizomes	Arrow Arum, Pickerelweed, Arrowhead
Lake George, Minnesota	Topsoil placement	Cattails, Woolgrass, Rushes and Sedges
Rancoas Creek, New Jersey	Plants	Arrow Arum, Arrowhead
Noti-Veneta, Oregon	"Introduced"	Duckweed
Willapa Bay, Washington	Transplanted	Saltmarsh Bulrush, Spike Grass
South Beltline, Wisconsin	Roots and Tubers	River Bulrush, Arrowhead, Burreed
South Beltline, Wisconsin	Mulching	Spike Rush, Aquatic Sedge, Bluejoint Grass, Burreed, Cattail, Lake Sedge
South Beltline, Wisconsin	Plants	Common Reed, Prairie Cordgrass
South Beltline, Wisconsin	Seeds	Smartweed, Marsh Milkweed, Water Smartweed, Marsh Dock, Woolgrass
Kenosha County, Wisconsin	Roots and Tubers	Burreed, Cattail, Arrowhead, River Bulrush, Sweetflag, Smartweed
Kenosha County, Wisconsin	Seeds	Bluejoint, Swamp Milkweed

Replanting may be performed using seeds, roots and rhizomes, propagules, or transplanted species. All types of replanting are used extensively. The seeds, roots, and rhizomes may either be distributed by hand or machine.

A factor considered in replanting is the density of the plants in the initial planting. Lee et al. (1976) reported that population densities of marsh grasses may reach 12,400 plants per hectare. The authors also reported planting *Phragmites communis* to densities equal to 49,400 plants per hectare in diked confinements in the Detroit area. (Note that *Phragmites communis* is a non-native invasive species along the U.S. Atlantic coast and Pacific Northwest.) The authors note that "the spread of most perennial marsh plants is very rapid when conditions for growth are optimal. Given adequate time to autonomously colonize containment areas, the number of propagules introduced could be kept to a minimum."

The feasibility of replanting to restore marshes or create new wetlands has been demonstrated. Although little is published that addresses replanting in response to impacts from discharges of oil or hazardous materials, the ability to transfer technology used on saltmarsh restoration activities to freshwater tidal marshes ensures that technically feasible actions for replanting will be available (see Section 2.2.1.1.3.2).

The use of muck/mulch as a seed bank is common practice (Bacchus, 1989; Clewell, 1981; Willard and Reed, 1988). The hope is that within the muck are seeds, roots, and rhizomes that will germinate or sprout into various indigenous species, effectively replanting the area.

Bacchus (1989) reports on incorporation of a muck layer as follows. Muck is taken from a donor wetland and placed in the new wetland in a layer at least 15 cm thick. This muck layer acts as a seed bank, containing not only seeds from the first wetland's species, but their root and rhizomes as well. This has the potential to allow revegetation of the same species that were present in the donor wetland. In considering the use of muck, impacts on the donor site need to be evaluated.

In general the muck layer reportedly is used for three reasons, it allows rapid reestablishment of a wide diversity of flora not readily available commercially; it simulates substrate conditions (e.g., pH and organic content) existing in the donor wetland, and it establishes beneficial soil microflora and fauna which improve the "vigor of the planted species." Bacchus (1989) additionally discusses various problems in incorporating the muck layer. These include failure of muck to produce perennial marsh species, inhibition of germination or seedling death by interactions with the muck, loss of seed bank effectiveness from storage of the muck, and contamination of the muck with undesirable species (e.g., cattails, primrose willow). Bacchus (1989) presented results from an unpublished study by Dr. Stephen Nielson who found that planting target species in sand substrate was preferable because the presence of a muck layer, even if uncontaminated, is "more conducive to invasion of non-native and nuisance species than sand or clay species."

Clewell (1981) discusses "mulching" using topsoil from natural swamps in connection with vegetation restoration on reclaimed phosphate mines. He recommended the use of topsoil in strips or piles.

Willard and Reed (1988) report on a study by Robertson in which three sites were prepared as follows: One site was left alone as a control, one was covered with "one foot of organic soil (mulch) borrowed from a marsh," and the third site was hand planted with wetlands plants. The mulched site "quickly approached the species richness and density of the donor marsh." The planted site did better than the control, but "suffered from invasion by weed species." Later mulching attempts by Robertson were apparently less viable, leaving the author to conclude that "technical feasibility apparently depends upon the number of propagules of invasive species in the mulch."

Availability of Services, Materials and Equipment

A number of capable, commercial specialist firms engage in wetland restoration. The growth of such firms has been spurred by wetland mitigation projects to offset wetlands lost for construction projects.

If the replanting method uses nursery-raised seedlings, sufficient lead time is required for the nursery to produce required numbers of seedlings.

Constraints

Planting activities should not begin until the contaminant in the sediment has degraded sufficiently to enable success (see Chapter 3).

In the case where propagules or seed bank material are gathered from the wild, suitable donor sites must be available. It is desirable that donor sites be located near the area being restored, to maximize acclimation and minimize logistics.

Pest plant species can be a problem in the restoration of freshwater wetlands. Foot and vehicular activity in the marsh area must be controlled in order to minimize further injury.

Future Restoration Actions

A certain amount of transplant mortality can be expected in a typical restoration planting project. Future restoration actions may include additional replanting.

Maintenance during the restoration project may also be required. Periodic efforts may be needed to eliminate pest plant species.

2.2.2.1.3.3 Soil Removal/Replacement

Removal of soil is performed primarily to remove residues of oil or other hazardous materials that are incorporated into the soils and cannot be removed in any other manner. This soil removal action was used on one riverine wetland in response to an oil discharge. Pimentell (1985) reported on a soil removal effort following a discharge of crude oil into the Little Panoche Creek in California. The soil was removed and stockpiled pending use or disposal. The soil was not replaced. The long-term plan was to allow natural sedimentation to return the marsh to its original state (see also Section 2.2.1.1.3). In effect, the issue of soil removal is not one of feasibility, but rather of doing excessive injury to the remaining habitat and associated costs. (Effectiveness is discussed in Chapter 3, and costs in Chapter 4.)

2.2.2.1.3.4 Vegetation Cropping

Cropping of vegetation is conducted primarily to remove oil residue that adheres to the reeds and leaves and cannot effectively be removed using other methods. Vegetation removal was conducted on two riverine wetlands in response to oil discharges. Foley and Tresider (1977) attempted to use mechanical cutters on the contaminated vegetation, but resorted mostly to hand cutting. Pimentell (1985) cropped vegetation and removed contaminated soil. The technical feasibility of cropping vegetation in an emergent freshwater wetland does not vary greatly from that of cropping in a saltmarsh (see Section 2.2.1.1.3.5.).

2.2.2.1.3.5 New Wetland Creation

The literature regarding the creation of new emergent freshwater wetlands focuses on the following:

- Creation of new wetlands to compensate for other wetlands destroyed by development (e.g., road building);
- Establishment of wetlands in dredge spoil areas; and
- Reclamation of wetlands previously drained for agriculture but being returned to wetland status under a conservation plan.

No literature was found that discusses new wetland creation in response to a discharge of oil or other hazardous material.

Building new wetlands typically requires some excavation to bring the surface level down to the water table, or diking and/or pumping to bring the water level up to the new wetland. Crabtree (1990) reported successful creation of freshwater emergent wetlands across the U.S. The USACOE has demonstrated the feasibility of building marshes in dredge disposal areas. Dikes are used for disposal impoundments to create the proper hydrologic characteristics (see Section 2.2.1.1.3.6.).

Piehl (1986), Rondeau (1986), and others have demonstrated the feasibility of restoring old wetlands that were drained for agriculture to their original state. In many cases, restoration was a simple matter of plugging the fixture installed to drain the water off the area.

Typically, restoration construction operations are coupled with replanting efforts, although the reclamation of drained wetland areas often leaves revegetation to natural recovery. (See 2.2.2.1.3.5. See saltmarsh restoration Section 2.2.1.1.3.2, replanting, and 2.2.1.1.3.6, new wetland creation.)

2.2.2.1.3.6 Low Pressure Flushing

See Section 2.2.1.1.3.7.

2.2.1.3.7 Bioremediation

See Section 2.2.6.1.3.5 for a general discussion of bioremediation.

2.2.2.2 Scrub-Shrub Wetlands

Restoration alternatives developed for scrub-shrub wetlands are the same as those for forested wetlands (See Section 2.2.2.3.) and include:

- Natural recovery;
- Replanting;
- New Wetland Creation;
- Flushing; and
- Bioremediation.

Most of the literature discussing restoration of freshwater wetlands dominated by woody plants focuses on forested wetlands. The restoration of a scrub-shrub wetland is very similar to restoration of a forested wetland (with the exception that shrubs rather that trees are the vegetation of choice). The technical feasibility of restoration of forested wetlands is considered in Section 2.2.2.3.

2.2.2.3 Forested Wetlands

Forested wetlands vary from wooded swamps to bottom land riparian habitats. Wooded swamps occur primarily in floodplains or shallow lake basins. Their soils are saturated to within a few inches of the surface or covered by several feet of water. The wetland may be flooded occasionally, seasonally, or for much of the year. Vegetation ranges from the water-tolerant wooded swamp varieties to typical bottom land species (e.g., cypress, tamarack, red oaks, gums). These characteristics affect the choice of actions for wetland restoration.

Restoration actions developed for forested wetlands include:

- Natural Recovery (monitoring);
- Replanting;
- Forested Wetland Creation;
- Low-Pressure Flushing; and
- Bioremediation

2.2.2.3.1 Oil Related Literature

No information was identified on restoration efforts in response to an oil discharge.

2.2.2.3.2 Non-oil Related Literature

The following reports discuss technical feasibility of restoration in non-oil discharge situations:

- Posey et al. (1984) provide information regarding upland and wetland creation and restoration at the Ravenwood shellrock mine. The discussion includes use of large tree spade for transplanting of adult trees;

- Brown et al. (1984) provide information regarding wetland reconstruction following phosphate mining, especially regarding the preparation of a peat substrate and vegetating with wetland species;

- Landin (1982) - This U.S. Corp of Engineers (USACOE) report discusses the restoration of mining lands in Louisiana to forested wetlands after regrading using local, water tolerant species;

- Weston and Brice (1991) discuss the restoration of hardwood wetlands after invasion by the exotic species. The exotic species, Brazilian pepper, was removed and the area replanted with indigenous species;

- Willard et al. (1990) provide information regarding restoration of riparian wetlands in the Midwest. The study primarily addresses restoration management (i.e., siting restraints, revegetation specifications, and long-term vegetation management requirements); and

- Jensen and Platts (1990) focus on the restoration of degraded riverine/riparian habitat in the Great Basin and Snake River regions.

2.2.2.3.3 Technical Feasibility of Restoration Actions

The technical feasibility of restoration actions is discussed below. Each action should include a monitoring program.

2.2.2.3.3.1 Natural Recovery

Monitoring of natural recovery is technically feasible in all cases. See Chapter 3 for a discussion of recovery potential.

2.2.2.3.3.2 Replanting

Replanting a forested wetland may be accomplished by seeding, planting seedlings, planting cuttings, and transplanting adult trees.

<u>Planting from Seed</u>

Direct seeding can be used in restoration projects. McElwee (1965) noted that direct seeding is cheaper than transplantation and the effects of "root disturbance" are eliminated. At the time of the author's report there existed many uncertainties to seeding, including site preparation, collection and storage, sowing rates, and protection from rodents.

Seeds must be collected when ripe and may require preparation prior to planting (i.e., soaking, scarifying, temperature treatment, etc., Willard et al., 1990). Seeds may be broadcast from the ground, boats, or aircraft.

In a report discussing seeding of oaks with acorns, Johnson and Krinard (1987) gathered acorns and collected information regarding seed handling, planting methods, survival, and competition. They noted that "sowing in the winter generally produces the best results" with one possible explanation being less loss to rodents. They note that satisfactory results were achieved from summer plantings and monthly plantings. The study notes that the major reasons for seeding failure are "flooding, droughts, residual herbicides, poor quality seeds, and animal damage."

Planting Seedlings

The technical feasibility of planting seedlings (young plants grown for transplanting) in various sizes (typically measured in gallons of the root ball) is recognized both commercially, i.e., nurseries regularly sell and plant such items, and in the literature regarding wetland restoration. Clewell (1981) noted in a study of restoration of reclaimed mine lands that the planting of seedlings is technically feasible for forest reestablishment and considered inexpensive so long as a mechanical tree planter is used. Landin (1982), in discussing the creation of a wetland on a dredge disposal site in Texas, also noted the technical feasibility of transplanting seedlings. Denton (1990), in a study of the growth rates and planting recommendations for cypress trees at forest mitigation sites, reports that this study found no difference in the survivorship of one-, three-, or seven-gallon trees.

Weston and Brice, (1991) discusses planting of species indigenous to central Florida following removal of an exotic species. The species planted were from a local nursery and hand-planted using unskilled labor from a non-profit youth organization. The species planted on the one hectare plot, their root ball size, and their survival rate are shown below.

Examples of Species	Root Ball Size	Number	Survival Rate
Red Maple (swamp area)	10 gallon	25	70%
Pond Cypress (swamp area)	15 gallon	38	98%
Pond Cypress (pond area)	15 gallon	20	98%
Pop Ash (pond area)	15 gallon	10	(na)
Swamp Tupelo (swamp area)	3-5 gallon	17	66%

Planting Cuttings

The use of cuttings (i.e., branches cut and planted without root growth) from various species to revegetate forests during wetland creation is documented. Jensen and Platts (1990) reported in a case study of a wetland created in Idaho, that willow cuttings used in restoring a riparian habitat had the "about the same" survival after one season as rooted stock. Available moisture in the soil was reported more important than the method of propagation. Cuttings of some species were found to survive better than others. Willow cuttings out-performed cuttings from some understory species used at the same site (e.g., choke cherry and dogwood). Carothers et al. (1990) reported using cottonwood and willow cuttings that were rooted at a nursery, bagged in one-gallon root balls, and used for wetland creation and restoration. They also discussed planting cottonwood and willow poles (cuttings) that were four to 20 feet long, cut from dormant living trees. (Non-dormant poles from which all leaves were removed could also be used.) The bases of the cuttings were "scored with an axe and dipped in a fungicide/hormone solution," after which they were buried in saturated soil.

Transplanting Adult Trees

Clewell (1981) discussed transplanting trees from natural swamps to reclaimed mining lands with a tree spade. The author noted that "tree spading of saplings up to 8 cm in diameter can be accomplished, though often with limited success." He noted that the operation is limited to soils firm enough to support the equipment.

Posey, Goforth, and Painter (1984) documented the feasibility of transplanting large, adult trees to a wetlands creation site using a large tree-spade. The study, located in central Florida, used a "Big John 78 Tree Spade" with a capacity to collect a 3,400 kilogram root ball with a two meter diameter. The authors report that trees to a height of nine meters could be cost-effectively transplanted using this method. The following tree species were transplanted with the tree spade.

The trees used in this study were taken from an adjacent area scheduled to be cleared and strip mined. Availability of indigenous species for transplant will vary depending on presence of trees on a donor site.

Carothers, Mills, and Johnson (1990), noted that "mature trees of any size can be boxed and moved." They note that while this action was used to salvage trees in areas to be developed, the action has not been used in restoration or creation projects. They state that "in some cases this action may be useful" but they note that cost is "its main drawback." The procedure requires pruning to reduce transpiration, digging trenches on all sides, building a box, watering for about two weeks, and cutting any tap roots followed by installing the box bottom. Maintenance (e.g., watering if the ground is not saturated) may be performed indefinitely. The authors report that survival rates average over 90 percent, regardless of tree size. The authors listed several species transplanted including mesquite, paloverde, ironwood, ash, willow, and various shrubs.

Species (Zone within Wetland)	Size (Height)	Number Moved	Survival Rate
Slash Pine (buffer zone)	15-30 feet	1,050	88%
Sable Palm (buffer zone)	15-35 feet	350	97%
Bald Cypress (littoral zone)	15-30 feet	80	75%
Pond Cypress (littoral zone)	5-8 feet	60	89%
Red Maple (littoral zone)	10-15 feet	30	86%
Red Maple (buffer zone)	15-25 feet	36	91%

2.2.2.3.3.3 Forested Wetland Creation

Many studies reported in the literature discuss the technical feasibility of creating a new forested wetland. The lands used for the new wetland range from natural stream or riverside areas (Bacchus, 1989; Willard et al., 1990; Jensen and Platts, 1990) to old strip mines (Posey et al., 1984; Brown et al., 1984; Landin, 1982).

Critical aspects of planning the creation of the forested wetland (Willard et al., 1990) include construction, hydrology, substrate, revegetation, fauna reintroduction, buffers, and long-term management. These items are discussed below.

Construction - Excavation (including removal of contaminated soils), contouring, and channel construction may be necessary to prepare a non-wetland area for a forested wetland (Willard et al., 1990). Contouring was used on old mine lands to return the topography to that of the land prior to strip mining (Jensen et al., 1990). As discussed by Willard et al. (1990) timing of the construction should be managed so as to minimize exposure of open ground subject to erosion.

The removal of exotic pest species prior to wetland restoration (Weston and Brice, 1991) or other nuisance species during restoration (Bacchus, 1989) are examples of preparation of the land prior to replanting. One study performed in Florida discussed the removal of an exotic species prior to replanting with indigenous species (Weston and Brice, 1991). Trees were cut with chainsaws and removed by hand. The vegetation was hauled to a waste recovery plant. All cut stumps were treated with a herbicide to stop regrowth. Felling of large trees may be accomplished by chainsaw, but will require full scale timber operations including skidders to haul out timber and logging trucks with lift arms to pick up and remove the logs.

Hydrology - Since wetland communities are "determined by hydrology," managing water levels is important. Willard et al. (1990) indicate a preference for natural site hydrology. However, permanent, low-maintenance water control structures such as levies or channels may be useful.

Substrate - The substrate is important in supporting the desired wetland functions (e.g., water retention) as well as supporting the desired vegetation (e.g., nutrients, compaction). Willard et al. (1990) point out that substrate can be altered by soil removal and/or replacement. Actions involving removing or modifying soils include:

- Off-site peat is brought in and used as a substrate (Brown et al., 1984);
- Off-site muck is brought in for substrate (Bacchus, 1989);
- Clay or silt may be added to a porous substrate in order to slow percolation (Kobriger et al., 1983); and
- Fertilizer should be added only to those substrates that are very infertile (Kobriger et al., 1983).

It should be noted that adverse impacts may occur to existing functioning wetland systems when they are mined for their substrate. This method should only be employed when substrates are collected from sites that are already slated for development or other adverse impacts. The objective of amending soils can also be achieved through the incorporation of organics (such as sterile straw or other commercially available products) into existing substrate. The use of peat should be avoided as the mining of these systems has resulted in their regional scarcity.

Revegetation - The proper vegetation selection is critical to the restoration effort. Typically with the creation of forested wetlands, an annual ground cover is established within which trees are planted. Timing is critical since replanting should be accomplished in the proper season to ensure high survival and first-year growth (Willard et al., 1990). Replanting is discussed under Option B above.

Reintroduction of Fauna - Typically in forested wetlands creation, fauna are allowed to recolonize naturally. Willard et al. (1990) note, however, that this passive reintroduction will only work if there are "adequate corridors to allow movement between existing populations and the project site."

Buffer Areas - Willard et al. (1990) state that "buffers are an essential component of wetland systems." These buffers serve to protect the new wetland from "outside disturbances" and act as corridors for floral and faunal reintroduction. The size of buffers needed depends on the nature of adjacent development or habitats.

Long-Term Management - Restoration must have a long-term management plan to achieve success (Willard et al., 1990). Vegetation management through mechanical control or controlled burnings is the most common form of long-term management. Willard et al. (1990) reports that managers often "wish to dredge wetlands." Dredging can significantly affect wetlands. The authors recommend either evaluating and modifying water control to flush sediments or accepting accumulation as a natural part of wetland dynamics.

2.2.2.3.3.4 Low Pressure Flushing

See Section 2.2.1.1.3.7.

2.2.2.3.3.5 Bioremediation

See Section 2.2.6.1.3.5 for a general discussion of bioremediation.

2.2.2.4 Bogs and Tundra

Bog type ecosystems in the U.S. are typified by the northern peatlands in Wisconsin, Michigan, Minnesota, and the glaciated Northeast (Mitsch and Gosselink, 1986). Similar peat deposits are found in the Pocosin area along the Virginia and Carolina coasts. Bogs are found in the Appalachian mountains of West Virginia. The tundra ecosystem in Alaska is similar to bogs because of low water interchange and similar characteristic vegetation (e.g., mosses).

Most bog ecosystems are the final stages of the "filling-in" of old lake basins formed from glacial activities. The centuries of debris deposited in basins forms the peat substrate that characterizes these systems. Bogs are characterized by a lack of nutrients and waterlogged, anaerobic, low pH conditions (Mitsch and Gosselink, 1986).

In Europe, late-stage marshes are classified as fens. Fens are characterized by more open waters, more nutrients, and "marsh-like vegetation" such as grasses, sedges, or reeds. The fens are transitional stages between marshes and bogs, but are, as noted by Mitsch and Gosselink (1986), classified as marshes under North American terminology.

The lengthy development time of the peat deposits in bogs is an important characteristic to understand in assessing human limitations in restoring affected bog systems. Hammer (1982) notes, in *Creating Freshwater Wetlands*, that efforts to establish bogs should begin by establishing marshes, which are successional stages to bogs.

Restoration actions presently available for bogs include:

- Natural Recovery; and

- Bioremediation.

2.2.2.4.1 Oil Related Literature

No information was identified on bog restoration efforts in response to an oil discharge. Brendel (1985) presented results from various restoration attempts for oil discharges on tundra around a trans-Alaska pipeline check valve.

2.2.2.4.2 Non-oil Related Literature

No information was identified on restoration efforts of bog ecosystems in non-oil situations.

2.2.2.4.3 Technical Feasibility of Restoration Actions

Actions considered include natural recovery and bioremediation, as discussed below.

2.2.2.4.3.1 Natural Recovery

Monitoring of natural recovery is technically feasible in all cases.

2.2.2.4.3.2 Bioremediation

Brendel (1985) reported on bioremediation attempts on tundra. The comparative analysis was conducted over a three-year period and involved various combinations of tilling, fertilizing, seeding, and bacteria placement (i.e., bioremediation). Bioremediation in the future may be considered as an action for restoring affected tundra (and possibly bogs). Presently, bioremediation is not fully developed, and, therefore, is not a feasible action in tundra or bog habitats. See Section 2.2.6.1.3.5 for a general discussion of bioremediation.

2.2.3 Vegetated Beds

Vegetated beds are classified as estuarine and marine macroalgal, seagrass, and freshwater aquatic beds. Macroalgal beds are classified as intertidal and subtidal (i.e., kelp) beds. Seagrass beds include temperate (e.g., *Zostera* spp. referred to as eelgrass, *Ruppia maritima*), subtropical, and tropical seagrass beds.

2.2.3.1 Macroalgal Beds

This section discusses intertidal macroalgal beds and kelp beds.

2.2.3.1.1 Intertidal Macroalgal Beds

Intertidal macroalgal beds occur on rocky and cobble intertidal areas. No documented case of restoration of intertidal macroalgal beds was identified. However, American Petroleum Institute (1991) suggests a possible scenario for transplantation in this habitat involving reestablishment of selected organisms, i.e., algae and selected fauna. This transplantation method includes collection from a suitable unaffected nearby area, transportation to the cleaned discharge site, and establishment at the restoration site. This is currently a rather speculative process, since little actual field implementation is documented in the literature. As with any transplanting activity, the effect on the donor site would need to be considered.

As intertidal macroalgal beds occur on rocky and cobble shorelines, technically feasible actions for rocky shores and cobble-gravel beaches are also feasible here. Considerations for the choice of actions will include evaluation of further injury caused by the action.

2.2.3.1.2 Kelp Beds

Most of the literature on kelp bed restoration focuses on those habitats dominated by the large brown alga *Macrocystis pyrifera* (Schiel and Foster, 1992). This habitat sustains a large number of dependant species. Restoration actions identified in the literature for injured *Macrocystis* kelp beds include:

- Natural Recovery;
- Replace with Transplants; and
- Vegetation Cropping.

Replacement can be used as an off-site replacement action if a suitable site is available. It should be noted that little or no research has been documented on other types of kelp beds (e.g. *Nereocystis*, *Laminaria*) and it is not known how applicable these actions are to these other systems.

2.2.3.1.2.1 Oil Related Literature

The available literature does not document any restoration attempts of subtidal kelp habitats performed due to oil contamination.

2.2.3.1.2.2 Non-oil Related Literature

Schiel and Foster (1992) describe attempts at kelp restoration. Historical restoration attempts identified in this paper include both "trial and error" experiments as well as more refined studies and applications of scientific actions. For example, many kelp habitat improvement projects were directed at restoring or expanding kelp forests in California over the past twenty years. Numerous unpublished reports were produced to document these efforts in regions including Los Angeles, San Diego (Point Loma), and Santa Barbara. Joint studies and restoration projects were conducted by the California Department of Fish and Game (CDFG) and Kelco Company, the largest kelp harvesting company in the state of California. Since 1987, the focus has been on injured kelp habitats in Santa Barbara among other regions in southern California (Schiel and Foster, 1992). Selected publications that review these restoration attempts are referenced in Schiel and Foster (1992). Kelp mitigation projects are also underway in the San Diego region as a result of kelp depletion by the San Onofre Nuclear Generating Station (California Coastal Commission, 1991). Another report documents restoration methods used to restore storm-injured kelp beds (CDFG, 1990).

2.2.3.1.2.3 Technical Feasibility of Restoration Actions

Exhibit 2.6 presents a summary of the state of technical feasibility for the actions considered for kelp bed restoration. Each action should include a monitoring program.

2.2.3.1.2.3.1 Natural Recovery

Monitoring of natural recovery is a technically feasible restoration action. The ability of an injured kelp bed to recover is discussed in Chapter 3.

2.2.3.1.2.3.2 Replace with Transplants

Transplanting was demonstrated as technically feasible for non-oil related injury to kelp beds. Transplanting involves the use of replacement substrate and plant material. Variations of this action include:

- Using mushroom anchor artificial growth centers (AGCs);
- Using mushroom anchor AGCs with transplants; and
- Stapling loose plants.

Exhibit 2.6 Overview of technical feasibility of kelp bed restoration.

	State of Feasibility	Availability of Services and Materials	Key Constraints	Future Restoration Efforts	Legal and Administrative Factors
Natural Recovery	Generally feasible	Generally available	Little Constraint	Replanting may be necessary	Coordination of monitoring activities
Replace with Transplants	Demonstrated as feasible under proper conditions	Specialist restoration expertise is required May be lag-time for anchor construction	Availability of spore population during deployment Unsuitable habitat conditions for planting Herbivory	Replanting due to transplant mortality	Permits
Vegetation Cropping	Demonstrated as feasible under proper conditions	Available	Possibility of additional injury	Possibility of collateral injury	No formal requirements

Artificial Growth Centers

Concrete anchor devices are used as artificial growth centers for kelp development in injured habitats. The anchors are placed on the substrate to attract plant spores. "Mushroom" concrete anchors are designed with a convex bottom and a flat top surface. This design provides a surface on which macroalgal spores can attach themselves in the absence of other suitable bottom substrate (e.g., rock). To stabilize spore attachment and growth, the anchors are fitted with rebar material (e.g., handles) that is set in the concrete. These "handles" help to secure a growing plant to the anchor. The mushroom anchors are deployed from a vessel with the use of a steel pole attached to tubing in the concrete anchors. The anchors are placed on the bottom. In sand bottom environments, the anchors are buried so that only the flat side of the anchor is exposed (CDFG, 1990). In northern, protected waters (i.e., Puget Sound), the placement of less sophisticated substrate (i.e., large rock, boulders) on otherwise featureless bottoms has proved suitable for kelp holdfasts.

Artificial Growth Centers with Transplant Material

The use of artificial growth centers (AGCs) with juvenile kelp plants (transplants) may accelerate recovery of an injured habitat compared to the use of anchor AGCs alone. This has been demonstrated as a technically feasible approach to kelp restoration (CDFG, 1990; Schiel and Foster, 1992). The plant material is secured with the use of a special type of wire that is attached to the anchor surface. The rebar handles offer support for the transplants. Transplant material provides an additional source of natural spores for recolonization as well as an immediate habitat for other organisms. Transplants are obtained by laboratory growth of plant spores to a desired development stage, followed by "outplanting" to the field. It is necessary for these plants to reach over 1 meter in height before they can be placed in the environment.

Staple Loose Plants to Habitat Bottom

Another demonstrated action for restoration of injured kelp beds involves securing loose plant material to the habitat bottom using large metal staples. This action was used in sandy bottom environments (e.g., California). Based on available literature, the best method for securing loose plant material is the use of two-foot long rebar staples with hose "barbs" attached to the ends (CDFG, 1990). The staples are driven through the loose plant into the substrate. The barbs provide a secure hold on the plants. This action was demonstrated as technically feasible when used in environments with soft bottom material. This approach, however, may not be as feasible in hard bottom kelp bed habitats.

Availability of Services, Materials, and Equipment

For the actions described above, the materials and equipment required can, in general, be easily obtained assuming that restoration takes place in an area close to boating and transportation suppliers. An exception to this may be the availability of concrete anchors, which have to be constructed by a manufacturer. In addition, the availability of transplant material for attachment to concrete anchors will depend on the capability of local plant nurseries to supply the required material.

The majority of kelp restoration projects documented in the literature are located in California. As a result, specialist personnel experienced in the transplant actions described above are concentrated in this region. Schiel and Foster (1992) outline a comprehensive bibliography of studies on the kelp community, identifying a number of technically qualified persons who could oversee restoration. The placement of anchors and transplant material also requires vessel operators, divers, and other technical personnel. These labor requirements can be generally fulfilled in coastal communities.

Constraints

In general, restoration should occur in areas where kelp grew in the past. In planning restoration, the desired growth density should be chosen so that it is in within normal range (i.e., that which is observed naturally in the region). When artificial growth centers are used, the most effective time period for deployment is from September to December, the peak colonization period for *Macrocystis* spores. Anchors with transplants should be used where macroalgal spores are not available for recruitment, such as in the late winter and spring when species other than kelp might colonize the growth centers. When anchors are used in sand bottom habitats, it is important that the anchor not bury completely in the sand so that an exposed surface is available for new algal spores to develop. This may be prevented by the use of heavier anchors (e.g., 45-65 pounds each), which are better able to stand up to wave surges and other forces that may cause burial. Further, heavier anchors are able to secure the largest plants expected to develop within a year from deployment.

Suitable habitat and environmental conditions are required for maximum growth, survival, and voluntary recruitment of planting material. The technical feasibility of planting activities is hampered by high sedimentation, which prevents light and nutrients from reaching the plants, high water temperature, high levels of turbidity, which can scour and leave abrasions on the plants and prevent macroalgal spores from colonizing on substrate, and poor quality substrate, which can affect the character of algal stands.

Future Restoration Actions

Future restoration actions may be needed (e.g., additional transplants) if recovery is slow.

2.2.3.1.2.3.3 Vegetation Cropping

Vegetation cropping of oiled *Macrocystis* stands has been documented as technically feasible for removing residual oil from kelp beds in the context of cleanup operations (Johnson and Pastorok, 1985; API, 1991). However, there are no documented cases where kelp vegetation cropping has been performed in either oil discharge- or non-oil discharge related restoration projects.

Vegetation cropping has the potential to cause further injury to the habitat. However, this injury can be mitigated by taking certain actions in conjunction with the cropping operation. These include, leaving untouched kelp strips among the clear cut areas, harvesting only the minimum length of kelp necessary, and selective thinning of kelp plants (Johnson and Pastorok, 1985; API, 1991).

Vegetation cropping is only appropriate where the macroalgal species involved, such as Macrocystis spp., does not grow from the tip of fronds. This needs to be evaluated before considering this action for other species.

2.2.3.2 Seagrass Beds

Seagrass beds in the U.S. may be classed as either temperate and subartic or subtropical and tropical. Eelgrass (*Zostera marina*) is in most cases the dominant species of temperate and subartic beds, extending from near the Arctic circle on both coasts of North America south to North Carolina on the east coast and to the Gulf of California on the west coast. Dominance by *Ruppia maritima* is also common (worldwide). In the subtropical and tropical climatic regions (i.e., Florida, the Gulf of Mexico, and the Caribbean), several types of seagrass are found. The dominant species in these regions include turtlegrass (*Thalassia testudinum*), Cuban shoalgrass (*Halodule wrightii*), and manatee grass (*Syringodium filiforme*).

Identified actions for seagrass restoration include:

- Natural Recovery (monitoring); and
- Replanting.

Replanting can be an on-site restoration action or an off-site replacement action, if a suitable site is available.

2.2.3.2.1 Oil Related Literature

Based on a search of published literature and communications with technical experts, there are no documented cases where seagrass habitats injured by oil contamination have been restored (Zieman et al., 1984; Fonseca, 1991; Thayer, 1991).

2.2.3.2.2 Non-oil Related Literature

Seagrass restoration is extensively documented in the literature for non-oil related habitat impacts. These publications include:

- Thorhaug and Austin (1976) discuss results of historical eelgrass projects including methods used and habitat conditions;
- Fonseca et al. (1979) summarize results of a restoration effort performed in an eelgrass habitat injured from scallop dredging;
- Phillips (1980) provides restoration planting guidelines for various types of seagrass restoration;
- Thorhaug (1980) describes historical restoration attempts for seagrass replanting including results, rationale for methods, and related costs;
- Fonseca et al. (1982b) report guidelines for a specific restoration action to transplant eelgrass. This paper provides updated information to Phillips' (1980) guidelines;
- Phillips (1982) presents an overview of seagrass ecosystems and provides a review of specific projects and methods used for eelgrass restoration;
- Thorhaug (1986) provides an overview of historical seagrass restoration efforts, including eelgrass projects, and suggests areas for further research and improvement;
- Thorhaug (1989) reviews seagrass restoration in terms of its ecological and economic benefits to fisheries and aquaculture. Historical seagrass restoration attempts are reviewed;
- Fonseca et al. (1990a) summarize an eelgrass transplanting project and compare results to recently colonized and long-time existing eelgrass habitats;

- Lewis and Phillips (1981) discuss an experimental seagrass restoration project performed in the Florida Keys using various types of planting materials;

- Thorhaug (1981) describes the reliability of several seagrass restoration attempts performed in south Florida, the west Florida coast, the Texas coast, and on the upper Gulf of Mexico;

- Derrenbacker and Lewis (1982) evaluate three methods and Thorhaug (1983) reviews and evaluates the technical feasibility of seagrass planting in an area off Key Largo, Florida, which had been affected by water pipeline installation;

- Durako and Moffler (1984) assess the technical feasibility of seagrass restoration using varied growth mediums and anchoring systems;

- Hoffman et al. (1982) review several historical restoration projects performed in Tampa Bay on affected seagrass communities;

- Fonseca et al. (1987a) evaluate the use of basic ecological data for application to the decisionmaking process when implementing seagrass restoration;

- Fonseca et al. (1987b) report on seagrass transplants that were conducted at sites across a broad geographic area in order to assess seagrass shoot generation and coverage rates under different geographic and environmental conditions;

- Thorhaug (1987) describes four large-scale implementation attempts to restore injured seagrass habitats affected by dredging of an intra-coastal waterway channel and construction activities; and

- Fonseca et al. (1990b) report on experimental research conducted on seagrass restoration in Lassing Park, Florida to create a seagrass habitat on a recently filled navigation basin.

2.2.3.2.3 Technical Feasibility of Restoration Actions

Exhibit 2.7 presents a summary of the technical feasibility for each restoration action. Each action should include a monitoring program.

Exhibit 2.7 Overview of technical feasibility of seagrass restoration.

	State of Feasibility	**Availability of Services and Materials**	**Key Constraints**	**Future Restoration Efforts**	**Legal and Administrative Factors**
Natural Recovery	Generally feasible	Generallly available	Litte constraint	May need to consider replanting	Coordination of monitoring activities
Replanting	Demonstrated as feasible for *Thalassia* under proper conditions	Appropriate donor sites are required Specialized technical expertise to oversee project is required	Planting may be seasonally limited Herbivory	Replanting due to transplant mortality	Permits may be required for both removal of transplant stock and planting

2.2.3.2.3.1 Natural Recovery

Monitoring of natural recovery is a technically feasible action. The recovery of injured seagrass ecosystems is evaluated in Chapter 3.

2.2.3.2.3.2 Replanting

For restoration of seagrass habitats, transplanting can be performed. This method has been attempted for many years and more information is becoming available as the actions continue to develop. Three primary types of propagules are used for replanting, plugs and turfs, shoots (or bare roots), and seeds.

Plugs and Turfs

A plug contains seagrass blades, roots, rhizomes, and sediment. It is extracted from a natural bed and transported to an excavated hole. Small plugs can also be transferred to peat pots, which are then planted in the sediment. Plugs may be anchored in high energy areas using cement collars that weigh the transplant down or by covering the transplant with chicken wire. The plug transplant minimizes "trauma" to the roots and rhizomes of the seagrass plant because it entails removing a large portion of the sediment mass with the plant. This method provides seagrass plants with immediate sediment stabilization.

A coring mechanism is used to perform the transplant of a seagrass plug. In transplant experiments a PVC coring tube (approximately 10 cm in diameter and 51 cm in length) was used to obtain a seagrass plug from a donor seagrass bed and insert it (with the plug intact) into the receiving sediment. The cored seagrass plugs are installed using a tree-planting bar, which is used to loosen sediment. The coring transplant operation is most efficient when a team of individuals work in the preparation, handling, and insertion of planting materials (using SCUBA gear is necessary if the planting is done below a certain water depth).

The peat pot method is presently being developed. Experiments are currently being conducted in order to evaluate its technical feasibility, cost-effectiveness, and success (Fonseca, 1991). This method uses small seagrass plugs as transplant material. Plugs are placed in square peat pots that help to support the plug and its roots. The potted plug is then planted into the habitat sediment. One advantage of this method is the ability to place fertilizer pellets in the pots to enhance the growth process. The peat pot method is considered a feasible means of transplanting mature seagrass stocks. However, the long-term success of this action remains uncertain (Fonseca, 1991; see Chapter 3).

The use of seagrass turfs (also known as "sods") entails cutting out a piece of sediment from the donor habitat and placing it in a shallow trench cut at the recipient site. Seagrass transplanting using turfs has been demonstrated as technically feasible (Thorhaug and Austin, 1976; Thorhaug, 1980; Phillips, 1982; and Thorhaug, 1986). The use of plugs and turfs is considered to be the most technically feasible approach for eelgrass restoration (Thorhaug and Austin, 1976; Thorhaug, 1986; Phillips, 1982).

Shoots (Bare Root)

Seagrass shoots are bare-root plants collected (for replanting purposes) from donor seagrass beds. The use of seagrass shoots for transplanting often requires anchoring by staples to stabilize the root system within the receiving sediment. It is common to combine several shoots together in order to provide a more complex root base. The logistics of using seagrass shoots are often simpler than handling seagrass plugs due to the lack of sediment associated with shoots. Transplants of seagrass shoots were attempted for many species of seagrasses and are technically feasible for eelgrass (Thorhaug and Austin, 1976; Thorhaug, 1980; Phillips, 1980 1982; Thorhaug, 1986; and Fonseca, 1990).

In the staple method, seagrass "planting units" are made from several seagrass shoots. The planting unit is then inserted into the sediment and stapled by hand with the aid of snorkel or SCUBA equipment. Stapling is more reliable than other shoot actions (Fonseca et al., 1990b). However, experiments using this method have shown greater loss rates in areas exposed to high turbidity and wave action during low tides.

Seeds

Seagrass seeds are also used to recolonize an injured seagrass habitat. Seeds are planted by hand after being gathered from a donor bed by separating the seeds from the fruit pod. Habitat areas with low turbulence are more easily seeded and have a greater chance of root formation and growth. Seeds can grow in either barren sediment, established seagrass beds, or in benthic algae (Thorhaug, 1989). The seeding action requires less labor than transplant actions, and so is potentially cost effective as a seagrass restoration action if abundant seeds are available. However, this method depends largely on the seasonal availability of seeds. There is difficulty in collecting seagrass seeds for replanting and such replanting efforts often result in poor germination rates, particularly for species other than *Thalassia* (Thorhaug and Austin, 1976; Fonseca et al., 1979; Thorhaug, 1980; Phillips, 1982; and Thorhaug, 1986). Thus, it is presently only technically feasible for *Thalassia*.

Availability of Services, Materials, and Equipment

Seagrass plant materials are commonly hand-collected from a "donor" seagrass site using shovels and other tools, depending on the type of plant material to be collected. Technical expertise is required to oversee projects. This would typically involve specialists from academia, government agencies, or firms with experience in seagrass restoration. In addition, divers may be required if restoration is conducted at deeper water depths.

Constraints

Because of variation in growth by season, planting times must be coordinated with the local climatic conditions (Fonseca, 1990a). For example, the fall season is generally considered the best time to plant eelgrass (Fonseca et al. 1979).

Future Restoration Actions

Replanting may be necessary due to transplant mortality.

2.2.3.3 Freshwater Aquatic Beds

Restoration actions consist of:

- Natural Recovery; and
- Replanting

2.2.3.3.1 Natural Recovery

Monitoring of natural recovery is technically feasible. See Chapter 3 for a discussion of recovery.

2.2.3.3.2 Replanting

Replanting of freshwater aquatic beds appears to be technically feasible. However, little documentation exists describing restoration efforts (see Section 3.2.3.3).

2.2.4 Mollusc (Oyster) Reefs

Mollusc reefs include oyster reefs and mussel reefs. Oyster reefs are more prevalent than mussel reefs and support an established fishery. Mussel reefs primarily exist in the more temperate regions and support a less significant fishery. Most previous restoration efforts for mollusc reefs have been for oyster reefs and that is the focus of the discussion here. No literature on mussel reef restoration was identified.

Natural oyster reefs are created when layers of oyster shells cover the substrate, forming a bed. The bottom substrate, or cultch, is commonly a hard smooth surface such as rock bottom or created from deposits of oyster shells. Oyster spat (larvae) attach to the cultch when settling. The oyster reef is formed as the elevation of the bed rises, resulting from the accumulation of dead shells underneath the new spat. Productive oyster reef habitats are generally characterized by cultch mounds that have high elevations and large quantities of exposed surface shells (Morales-Alamo et. al., 1990).

The restoration actions identified in the literature for oyster reef restoration include:

- Natural Recovery;
- Reef Reconstruction; and
- Oyster Reseeding.

These actions can be used for direct restoration or replacement if a suitable site is available.

2.2.4.1 Oil Related Literature

In no cases where oil contamination to oyster habitats was been documented, were direct restoration projects attempted, other than allowing natural recovery to occur (Benefield, 1992; Heil, 1992; Ray, 1992; Soniat, 1992).

2.2.4.2 Non-oil Related Literature

Available literature primarily identifies restoration practices for oyster reefs following natural and human-related adverse influences including hurricanes, siltation, dredging, barge groundings, and other non-oil impacts. The technical feasibility of restoration is addressed in Berrigan (1988a,b, 1990), Bowling (1992a,b), Hofstetter (1981), and Marwitz and Bryan (1990).

2.2.4.3 Technical Feasibility of Restoration Actions

Exhibit 2.8 provides a summary of restoration actions identified for oyster reef restoration. Each action should include a monitoring program.

The following restoration actions are applicable to oyster reefs in both the intertidal and subtidal zones. The literature on oyster reef restoration focuses primarily on reefs in intertidal areas. However, experiments have shown that the success of restoration performed on reefs located both inshore and offshore is not significantly different (Haven et. al., 1987).

Exhibit 2.8 Overview of technical feasibility of mollusc reef (oyster) restoration.

	State of Feasibility	Availability of Services and Materials	Key Constraints	Future Restoration Efforts	Legal and Administrative Factors
Natural Recovery Monitoring	Generally feasible	Generally available	Little constraint	Reef restoration action could be warranted due to slow recovery	Coordination of monitoring activities
Reef Reconstruction	Demonstrated as feasible	Shell is limited in supply; alternative materials are available	Site selection in the case of off-site restoration	Additional restoration may be necessary if recovery is slow	Coordination with habitat management authorities Permits may be required
Oyster Reseeding	Demonstrated as feasible	Seed oysters may be limited in certain regions	Residual contaminants; poor water quality	Additional seed oysters may be required due to level of mortality	Coordination of activities with habitat management authorities

Exhibit 2.8 (continued)

Vegetation Cropping	Vegetation Cropping		Generally feasible	Readily available	Possibility of further injury	Collateral injury may result in additional restoration	No formal requirements
New Wetland Creation	New Wetland Creation	Soil Removal/ Replacement	Technique has been developed	Variable, since projects may range from simple services to massive construction projects	Acquisition of site Establishment of hydraulic regime Controlling contaminants Pest species	Most viable projects have extensive programs of evaluation and mid-course correction	Permit procedures Negotiation for site acquisition
Low Pressure Flushing	Low Pressure Flushing	Vegetation Cropping	Feasible in limited circumstances	Available from oil spill cleanup contractors	Access to marsh interior	Additional restoration due to damage	No formal requirements
Bioremediation	Bioremedia-tion	New Wetland Creation	Technique is currently being developed	Services and equipment generally available	Few people have strong bioremediation expertise in estuarine and marine systems Work crew access needed Possible eutrophication effects	None expected	Permits required

Several oyster reef restoration actions were performed where the oyster resources are important to the fishing industry (e.g., Maryland, Florida, Gulf of Mexico). These restoration actions proved technically feasible (Berrigan, 1990; Bowling, 1992a,b). The restoration of oyster habitats typically involves:

- Reconstruction of oyster reef substrate using alternative materials; and/or

- Reestablishment of the injured habitat or other comparable site with seed oysters.

2.2.4.3.1 Natural Recovery

Monitoring of natural recovery for oyster reefs is technically feasible in all cases. See Chapter 3 for a discussion of recovery potential.

2.2.4.3.2 Reef Reconstruction

The objective of reef reconstruction is to provide a clean, hard substrate for oyster spat (settled larvae) colonization and growth. The placement of suitable substrate, or cultch, is a action for increased oyster colonization if it is performed in areas with appropriate bottom types (i.e., conducive for immediate oyster set) (Kennedy, 1991; Webster and Meritt, 1988). In general, oysters settle best on bottom that is firm, such as those of rock, stone, or shell. Firm or sticky mud is also a suitable bottom type, but sandy habitats are often subject to shifting, which can result in sedimentation and siltation of the oysters.

Suitable bottom types are often cultivated in oyster producing grounds by laying down a firm substrate "foundation" to support the colonization of oyster spat (Webster and Meritt, 1988). It is common practice among oyster habitat managers to apply cultch in historical oyster producing grounds in order to improve substrate characteristics and increase productivity.

Like bottom type, cultch material must also be of a firm consistency, suitable for larval attachment. Cultch planted in areas where natural oyster reproduction occurs stimulates larval setting and establishment of new oyster populations (Berrigan, 1990). Clean substrate, that which is free of sediment and other organisms, is preferable cultch material for maximum larval attachment.

Availability of Services, Materials, and Equipment

Alternative materials for creating suitable cultch for oyster colonization and growth have been experimented with extensively and include:

- Dredged or Fresh Shell (Oyster or Clam);
- Limestone;
- Cement Compounds;
- Slate and Shale;
- Gravel;
- Tire Chips; and
- Coal Ash.

Shell. Both oyster and clam shells have been used as cultch material. The shell is dredged from areas with large deposits of shell material or from other sources such as oyster processing plants.

For oyster reef restoration projects performed in Maryland, Florida, and Texas, shell was selected for use as the designated cultch material (Maryland Department of Natural Resources (MDNR), 1992; Berrigan, 1990; Hofstetter, 1981a,b; Marwitz and Bryan, 1990; Bowling, 1992a,b). In these projects, shell was considered a superior material because of its ability to form a firm base and attract numerous oyster settlements. It is also preferable because of its greater surface area per unit volume, allowing more space for the settlement of oyster larvae (Ray, 1992). It is recommended that shell be planted as cultch at places where maximum larval sets are expected to occur and at favorable times of the year (Hargis and Haven, 1988).

Although shell is the preferable material for oyster cultch, availability in some regions (e.g., Gulf of Mexico) is limited due to restrictions on dredging activities (Abbe, 1992; Benefield, 1992; Judy, 1992; Heil, 1992; Ray, 1992; Soniat, 1992). Experiments were conducted on other materials. These alternatives, discussed below, are not currently in widespread use, but results of recent experiments conclude that some may be viable alternatives (Soniat et al., 1991; Haywood and Soniat, in press).

Limestone. Limestone was recently tested as a potential cultch (Soniat et al., 1991). Limestone may be a feasible alternative to shell because experiments show that limestone is successful in attracting oyster larvae, most likely due to its calcium carbonate composition, the availability of limestone is not limited, and costs are comparable to or lower than shell.

In soft bottom habitats, limestone is not as cost-effective as shell since limestone has a higher weight per unit of volume, thereby requiring a greater volume of material to compensate for sinkage. Yet in tests comparing limestone and shell where sinkage is not a factor (i.e., in hard bottom habitats), limestone proved the preferred cultch material because of its lower cost per unit of volume (Soniat et al., 1991). However, limestone has not yet been used for a large-scale restoration project (Soniat, 1992; Benefield, 1992). In future restoration projects, it is expected that limestone will prove to be a biologically feasible, cost-effective, and environmentally benign alternative to shell as oyster cultch (Soniat et al., 1991), particularly in areas where shell cultch is limited.

Cement Compounds. Other alternatives to shell for oyster cultch include the use of cement compounds, crushed road bed (concrete with some asphalt), gypsum, and "gypment" (gypsum and cement mixture). In a study that compared the effectiveness of crushed road bed and cement with shell as oyster cultch, the shell attracted more oyster spat than the concrete/asphalt mixture (Soniat et al., 1991). In addition, this material is much heavier than shell and results indicated that the road bed may contain trace pollutants.

In the same study, gypsum (a by-product of fertilizer production) was also tested as an alternative to shell and found to attract oyster larvae. Gypsum is relatively lightweight and inexpensive. However, gypsum was extremely soluble in water, therefore not feasible for cultch. A later experiment tested a stabilized gypsum-cement compound ("gypment") as an alternative cultch (Haywood and Soniat, in press). The rate of dissolution of gypment was observed and its effectiveness compared with limestone and shell. Preliminary results indicate that gypment is suitable as cultch, performing as well as or better than shell in attracting oyster spat. Gypment is also acceptable in material weight (i.e., lighter than limestone) and solubility (the stabilizing cement makes the compound insoluble). Gypment is not yet manufactured or used on a large-scale basis, but should be a viable alternative in the future.

Slate and Shale. The use of slate and shale as alternative cultch material was examined (Haven et al., 1987; Mann et al., 1990). Slate was investigated because of its composition (i.e., it is a hard substrate), low cost, and plentiful supply (Haven et al., 1987). It was found that slate attracted a much lower density of oyster spat than shell. Expanded shale was found less effective for oyster larvae settlement in comparison to shell (Mann et al., 1990). However, shale has potential value as a bottom stabilizer prior to substrate placement. The results of these studies favor the use of shell over both slate and shale as a setting medium, but also note that these materials offer a greater per unit area for spat recruitment than shell.

Gravel. The use of gravel as a substitute for oyster cultch was tested and compared to shell, limestone, and concrete (Soniat et al., 1991). The resulting minimal larval setting indicated that gravel is not a biologically acceptable material and thus not a viable option for oyster cultch.

Tire chips. In a study where tire chips (shredded tire casings) were used as an oyster reef substrate replacement, it was found that tire chips are less effective than shell because of dispersal of tire material by currents and wave action (Mann et al., 1990). Other applications of recycled rubber as cultch material are currently being investigated by oyster reef management teams (Judy, 1992).

Coal Ash. Coal ash, a by-product of coal powered plants, is presently being investigated as cultch. A recent study performed in Texas indicated that coal ash may be an acceptable action in terms of effectiveness, availability, and cost (Ray, 1992; Soniat, 1992). However, this material is not yet used on a large-scale basis.

Expertise on oyster habitat management and restoration is available in state fishery management agencies and the scientific community in the primary oyster regions. Reef reconstruction generally requires marine construction services for the placement of materials (i.e., barges and hoses). These requirements are available in most coastal regions.

Constraints

If replacement of oyster reefs is the chosen alternative, it is important to select sites where spat setting was successful in the past. For successful recruitment of oyster spat, placement of reef substrate should be timed with the seasonal cycle of oyster spat settlement. For example, substrate that is planted too early may be fouled by other organisms or by sedimentation, reducing space for larvae to set. If reef substrate is planted too late in the season, the peak oyster settlement period may be missed.

Future Restoration Actions

Future restoration actions, such as the placement of additional reef materials, may be needed if recovery is slower than expected.

2.2.4.3.3 Oyster Reseeding

The technical feasibility of reseeding oyster beds has been demonstrated by regional oyster management agencies (MDNR, 1992). It is common practice for managers of regional oyster fisheries to cultivate seed oyster grounds for annual restocking purposes. Seed oysters are small, not fully-developed oysters which are raised in hatcheries or specially designated natural oyster beds. The rate of oyster reef restoration may be enhanced by transplanting seed oysters onto the reef site or to an established reef habitat elsewhere.

In documented restoration actions performed for injured oyster reef habitats, restocking the reef with seed oyster was not a priority action. The literature indicated that the primary objective of the restoration projects was to reestablish the habitat through replacement of the substrate. The seeding was demonstrated as technically feasible in areas where natural occurrences and fishing resulted in depleted oyster stocks (Munden, 1974; MDNR, 1992).

<u>Availability of Services, Materials, and Equipment</u>

Seed oyster stock used for reseeding is commonly supplied by neighboring seed beds that are cultivated by independent (commercial) oyster harvesters or regional management agencies. Seed stocks are generally locally available, except in cases where all stocks in the proximity of the injured reef area are destroyed or not ready for cultivation. In these situations, seed stock may be obtained from other regions. Proper equipment and expertise required for obtaining and transporting seed oysters are generally accessible.

<u>Constraints</u>

The use of seed oyster stock to reestablish an injured oyster bed may not be feasible when the injured (i.e., contaminated) habitat has not fully recovered to suitable environmental conditions for growth. For example, residual oil or other contamination in the water may affect the development of oyster stock and cause mortality to the juvenile oysters.

<u>Future Restoration Actions</u>

Further reseeding or new reef creation may be needed if recovery goals are not met.

2.2.5 Coral Reefs

Restoration actions for coral reefs include:

- Natural Recovery;
- Reconstruction of Reef Substrate; and
- Coral Transplants.

Reef restoration may be performed as a direct restoration action or as replacement action if a suitable site is available.

2.2.5.1 Oil Related Literature

Little or no empirical work has been done in the area of restoring oil-injured coral reef habitats (Bright 1991; Gittings, 1991b; Hudson, 1991).

2.2.5.2 Non-oil Related Literature

Restoration actions that are reported in recent academic literature focus primarily on the rehabilitation of reef areas injured as a result of structural injury, such as from ship groundings. The reported restoration approach entails the transplanting of live coral pieces or groups of corals from a donor site to an injured reef area. This method is documented as technically feasible (NOAA, 1991b; Fucik et al., 1984). One reef restoration action that is recommended in the literature for use on oil-injured coral reefs involves the transplanting of coral colonies onto the reef frame (Fucik et al., 1984). However, this method has not been employed in oil-related reef injury situations.

2.2.5.3 Technical Feasibility of Restoration Actions

The technical feasibility of restoration actions is summarized in Exhibit 2.9 and is discussed below. Each action should include a monitoring program.

2.2.5.3.1 Natural Recovery

Monitoring of natural recovery is technically feasible. See Chapter 3 for a discussion of recovery.

2.2.5.3.2 Reconstruction of Reef Substrate

Injured reef substrates may need to be reconstructed or reestablished. For example, impact from a ship grounding may fracture the calcium carbonate substrate that forms the coral reef framework. An approach commonly used to restabilize such injured reefs is the use of a calcium carbonate-based cement to fasten broken pieces of the reef back on to the injured areas. The cement used is of similar chemical makeup to coral and is compatible with reef organisms.

Experimental evidence supports the technical feasibility of this action to restore the reef framework (Hudson, 1991). Live corals can recolonize the injured areas where cement is used to restabilize the habitat. The additional support and relief offered by restabilizing the reef substrate enhances the ability of the coral community to regenerate after injury occurs. Relocation of large dislocated sections, such as coral colonies or "coral blocks," onto the reef structure recreates the complex arrangement of the natural coral reef.

Exhibit 2.9 Overview of technical feasibility of coral reef restoration.

	State of Feasibility	**Availability of Services and Materials**	**Key Constraints**	**Future Restoration Efforts**	**Legal and Administrative Factors**
Natural Recovery Monitoring	Generally feasible	Generally available	Little constraint	Reconstruction and transplants can be considered if necessary	Coordination of monitoring activities
Reconstruction of Reef Substrate	Demonstrated as feasible for structural injury	Specialized scientific expertise required	Suitable environmental conditions required	Transplants can be considered if necessary	Permits required
Coral Transplants	Demonstrated as feasible for structural injury	Transplant stock may be limited	Proper donor mateiral is required	Additional restoration due to transplant mortality	Permits required

Availability of Services, Materials and Equipment

The calcium-based cement used to stabilize the reef structure is a widely-available product (Hudson, 1991). Divers are required to perform the reconstruction. Such services are generally available in areas where there are coral reefs. Scientific expertise will be needed to oversee the operations.

Constraints

There are few constraints on this action, providing care is taken not to cause additional injury. Suitable environmental conditions are required, including that the site be free of contamination.

Future Restoration Actions

If restoration goals are not met, transplants may be considered.

2.2.5.3.3 Coral Transplants

Reef restoration using live coral colony transplants was suggested for oil-injured coral reefs (Fucik et al., 1984), and demonstrated as technically feasible for reefs injured from structural impact.

Coral transplants were used to rebuild an injured reef in a restoration project described by Hudson and Diaz (1988). A higher rate of mortality was observed for transplanted soft corals than for hard corals because of the difficulty of relocating specimens without incurring injury to delicate holdfast tissue. Transplanting hard corals does not pose this problem due to the protection of the tissue by a stony skeleton (Hudson and Diaz, 1988). Full recovery of injured coral reefs restored by the use of transplants is not documented in the literature, primarily because of the length of time required for full growth and natural recovery of coral specimens. (See Chapter 3 for discussion of recovery.)

Availability of Services, Materials and Equipment

The transplant approach to recolonization involves pruning uninjured live coral from nearby reef structures and fastening them to the injured reef. The availability of coral colonies for transplant material is dependent upon the quality and complexity of existing coral stock in the region where the injury occurred. The material used to fasten coral transplants to the injured reef area is a calcium-based cement, a product widely available (Hudson, 1991).

Past restoration efforts of injured coral reefs documented in the literature represent a collaboration of individual scientific expertise. Such expertise would have to be sought from the scientific community.

Divers are required to hand-carry the coral specimens from the boat to the transplant plot and to cement the transplants in place. Such services are generally available in areas inhabited by coral.

<u>Constraints</u>

A review of past coral reef restoration actions using coral transplants identified several considerations for collecting and transplanting coral specimens and transplanting them to the reef framework. Before specimens are transplanted, the substrate must be prepared so that all loose sediment and rock debris and soft coral skeletons are removed from the area. Corals for transplant stock should be selected from existing reefs so that they represent the density and type of corals injured. Impacts to donor sites must be considered.

Coral species selected for transplant material should include specimens that are abundant and fast growing, have mature growth formations, and can be easily attached to the reef substrate. In addition, it is important that the corals selected for transplanting are those with mature reproductive functions and that sources of opposite gamete type are available within the transplant area (Fucik et al., 1984). These criteria ensure that the establishment of new coral growth occurs as quickly as possible. Technical feasibility is dependent on environmental conditions conducive to growth. For instance, observations from transplant experiments include a high survival rate in areas protected from violent wave action, and a reduced rate of recovery at a site chronically polluted (Fucik et al., 1984).

<u>Future Restoration Actions</u>

Additional restoration may be necessary due to mortality of coral transplants.

2.2.6 Estuarine and Marine Intertidal Habitats

This section discusses rocky shores, cobble-gravel beaches, sand beaches, and mud flats in estuarine and marine intertidal habitats. Many shoreline restoration actions are related to and sometimes considered part of discharge cleanup. Restoration is assumed to occur some time after the discharge incident, typically weeks to months, and may include removing residual contamination within beach sediments or removing residual stains or oiling on hard beach surfaces. Such actions may be properly motivated more by aesthetics or other non-biological values than by facilitating recovery of the intertidal biological community. In these cases, restoration is of non-biological services.

2.2.6.1 Intertidal Rocky Shore

Restoration actions consist of actions to remove residual contamination. This cleaning may be needed in addition to response actions because cleanup was inadequate. While it is generally not possible to remove or replace solid rock substrates, oiling or staining of rocky surfaces can often be cleaned to remove surface traces of material. The relevant actions for rocky intertidal habitat restoration include:

- Natural Recovery;
- Sand Blasting;
- Steam Cleaning;
- Flushing; and
- Bioremediation

Actions discussed for rocky intertidal habitats also apply to manmade structures, such as piers, bulwarks, breakwaters, etc.

2.2.6.1.1 Oil Related Literature

The evaluation of the technical feasibility of restoration alternatives in rocky shore intertidal habitats was conducted using several oil discharge-related literature sources. Owens et al. (1992), Hawkins and Southward (1992), Klokk et al. (1983), Anderson et al. (1983), van Oudenhoven (1983), Jahns et al. (1983), Lehr and Belen (1983), and Owens et al. (1983) discuss natural recovery following oil discharges in intertidal habitats. Literature by the Johnson and Pastorok (1985), Der (1975), and Benyon (1973) were used in the evaluation of sand blasting and steam cleaning, along with interviews with John Whitney of NOAA (Anchorage, AK) and Jacqueline Michel of Research Planning, Inc. (Columbia, NC), Anderson et al. (1983), Howard and Little (1987), and Owens et al. (1992) were detail flushing in intertidal areas. The use of chemical remediation in flushing operations is discussed by Fingas et al. (1991), Owens et al. (1992) and the American Petroleum Institute (1991); Richard Lessard of Exxon was also contacted and interviewed in this analysis. Finally, numerous sources cover the developing practice of bioremediation. Hoff (1992), Pritchard and Costa (1991), Greene (1991), Jones and Greenfield (1991), Lee and Levy (1991), Chianelli et al. (1991), Glaser et al. (1991), Minugh et al. (1983), Tramier and Sirvins (1983), Owens et al. (1992), and the U.S. Environmental Protection Agency (1990) appear in the literature. Interviews were also conducted with relevant bioremediation experts, including Russell Chianelli and James Bragg of Exxon and Alain Drexler and Paul Benn of Elf-Aquitaine.

2.2.6.1.2 Non-oil Related Literature

The literature that discusses restoration in intertidal habitats deals primarily with oil-related contamination. Thus, non-oil literature was not reviewed.

2.2.6.1.3 Technical Feasibility of Restoration Actions

The technical feasibility of each action is summarized in Exhibit 2.10 and discussed below. Note that the findings in Exhibit 2.10 apply equally to lacustrine rocky shore habitats, subsequently presented in Section 2.2.8. Each action should include a monitoring program.

2.2.6.1.3.1 Natural Recovery

Monitoring of natural recovery is a technically feasible action in intertidal rocky shore habitats. See Chapter 3 for a discussion of recovery.

2.2.6.1.3.2 Sand Blasting

In cases where residual staining remains on rocky surfaces following the initial cleaning and weathering of oil, it is technically feasible to use sand blasting to remove the stains. Sand blasting involves scouring the affected surface with an abrasive (e.g., sand) propelled by compressed air. Although sand blasting has had limited use in restoration efforts historically, Der (1975) noted that sand blasting rocks following the 1969 Santa Barbara oil well blowout was the "only treatment found effective" in cleaning the rocky habitat affected.

Sand blasting is expected to cause additional impacts, including the disturbance or mortality of organisms, contamination from unrecovered abrasive or oil, and removal of organisms from the habitat by high pressure jets (Johnson and Pastorok, 1985). Oil freed by sand blasting may combine with the abrasive to form a pavement-like coating on rocky surfaces and unrecovered oily abrasive may be ingested by organisms.

Sand blasting is considered primarily a polishing action in high amenity rock areas (e.g., areas with a great deal of recreational interest). The deployment of sand blasting equipment and personnel is fairly straightforward. Sand blasting crews will be deployed either by boat or land, depending upon access to the contaminated area. Necessary sand blasting equipment can be carried on a boat or transported by land to the affected shoreline. Work crews equipped with hoses then direct the abrasive to the contaminated areas.

Recovery of the loosened oil and abrasive may be problematic. Any freed contaminant that enters the water and floats may be contained by booms and sweeps and recovered with vacuum pumps. Similarly, oil and abrasive freed and remaining on shore may be vacuumed. Abrasive entering the water column, however, will likely not be contained and may present additional contamination problems.

Exhibit 2.10 Overview of technical feasibility of rocky shore restoration.

	State of Feasibility	Availability of Services and Materials	Key Constraints	Future Restoration Efforts	Legal and Administrative Factors
Natural Recovery	Generally feasible	Generally available	Generally available	May require cleaning of areas contaminated by freed oil	Coordination of monitoring activities
Sand Blasting	Generally feasible	Readily available nationwide	Lethal to biota surviving the oiling Strong wave action may limit operations Recovery of abrasive material Access to site important	Freed oil and/or abrasive may need to be recovered	None expected
Steam Cleaning	Feasible for small areas only	Readily available nationwide	Lethal to biota surviving the oiling Access from shore is needed	Freed oil may contaminate previously clean areas	None expected

Exhibit 2.10 (continued)

	State of Feasibility	Availability of Services and Materials	Key Constraints	Future Restoration Efforts	Legal and Administrative Factors
Flushing	Generally feasible	Generally available in coastal areas Chemical restoration agents available	Boats must be able to access site May not always remove all stains Removal of organisms Requires temporary storage site for recovered oil	Possible reoiling if freed oil escapes containment system	Permits may be difficult to obtain for chemical restoration
Bioremediation	Technique is currently being developed	Services and equipment generally available Possible difficulty in obtaining fertilizers	Few people have strong bioremediation expertise Work crew access to shore is critical Possible eutrophication effects	None expected	Thorough documentation of efforts Permits required

Availability of Services, Materials and Equipment

The services, materials, and equipment needed for sand blasting are readily available in all regions of the United States. Sand blasting can be performed by trained construction workers. These skills are readily available nationwide.

Constraints

Sand blasting rocky intertidal habitats in high wave energy environments may present certain operational constraints when the contaminated areas are not accessible from shore. Heavy seas will limit access by boat and may endanger work crews. The recovery of abrasive in a high wave energy area may be all but impossible. In cases where sand blasting must be conducted from the sea, the recovery of freed oil and abrasive may be difficult. This is also true for land-based efforts in which recovery equipment cannot operate.

Future Restoration Actions

Future restoration actions may be required in cases where a "pavement" forms on rocks from unrecovered oil and abrasive or when unrecovered abrasive poses a threat to organisms in the area. Recolonization of intertidal organisms may need to be enhanced. However, technically feasible actions to do so have not been documented to date.

2.2.6.1.3.3 Steam Cleaning

Discussions of steam cleaning are largely absent from recent restoration literature. This action involves using steam applied steadily and slowly by shore-based crews through hoses or some type of jet to loosen weathered oil clinging to rocks. Oil that is loosened by steam flows to lower sites on the shore where it is dissipated by wave action or recovered by work crews (Der, 1975). Steam cleaning is distinct from hot water, high-pressure spraying in that water is heated to boiling (212° F) in steam cleaning, but only to 140° F in hot water spraying (Michel, 1993).

The Johnson and Pastorok (1985) discusses this action, along with its possible impacts, which include the disturbance or mortality of organisms, contamination by unrecovered oil, crushing of organisms by personnel or equipment, disruption of sediments, or re-oiling of surfaces. Der (1975) notes that steam cleaning was used in rip rap areas following the blowout of an oil platform off of Santa Barbara in 1969. Although oil was loosened by the steam, the action left a black coating of oil on rock surfaces.

Steam cleaning is typically used as a polishing action in high amenity rocky areas (e.g., areas with a great deal of recreational interest). Steam cleaning is also appropriate for manmade structures, rip rap, and sea walls (Michel, 1993). Steam cleaning usually must be conducted from shore, since it is typically performed in the upper intertidal zone only (Michel, 1993). This is because steam must be directed at stains steadily, and must be deployed near the stain. All necessary equipment may be carried on a boat or transported by land to the shoreline. Work crews equipped with hoses or jets direct the steam to the contaminated areas.

Recovery of the loosened oil is frequently accomplished by vacuuming oil from water or rocks. If oil is allowed to flow into the sea, it must be contained using booms or sweeps to prevent additional contamination of other areas.

As in the case of sand blasting, steam cleaning is technologically fairly simple. Therefore, few factors influence its technical feasibility.

Availability of Services, Materials and Equipment

Materials and equipment should be readily available nationwide to perform the steam cleaning process.

Constraints

Since operators must be able to direct a steady flow of steam to the weathered oil, steam cleaning is a slow and time-consuming procedure. Therefore, this action is only feasible for small areas. Crews are also likely be required to operate from shore, since they will operate primarily in the upper intertidal zone. Technical feasibility of this method depends on the access to oiled rocks. It is necessary that crews work unimpeded in contaminated areas for extended periods of time to apply this action effectively.

Steam cleaning may also present occupational health and safety constraints, since workers will be operating adjacent to water heated to boiling. Care must be taken and protection provided to prevent burns to workers.

Future Restoration Actions

Except when oil recontaminates previously-cleaned or unoiled areas, future restoration actions is unnecessary. Since steam cleaning is lethal to intertidal organisms, recolonization may need to be enhanced. However, technically-feasible actions to do so have not been documented to date.

2.2.6.1.3.4 Flushing

Flushing in rocky intertidal habitats, also referred to as "spot washing," can include the use of ambient or heated water to remove residual oil coatings from hard substrate. In an intertidal zone, the loosened substance is likely washed into the nearby water body where it is contained and removed (Owens et al., 1992).

Techniques used in the past have included low, medium, and high pressure flushing. This discussion focuses on medium pressure since it has evolved as the preferred method. The factors affecting technical feasibility for other pressures or temperatures would be similar. This section also discusses the relatively recent development of chemical restoration methods that are used in conjunction with flushing.

The use of pressure washing in the field is described in Anderson et al. (1983) and Howard and Little (1987). Anderson et al. describe efforts following the principal cleanup efforts in the *Amoco Cadiz* discharge off France. Once mousse was removed from the area, the cleanup team focused on removing stains from beaches and rock faces. Following attempts with low-pressure and high-pressure flushing, those working on the restoration settled on a medium-pressure flushing (approximately 50 psi) method as the most effective, least expensive, and safest alternative. Howard and Little (1987) studied the cleaning effectiveness and biological impacts of low-pressure flushing of very fine intertidal sediments. They indicate that low-pressure flushing is effective where oil is viscous, less than 10 cm thick, and sediments are relatively firm. Further, sediments must be sufficiently thick to avoid erosion. Although Howard and Little's work was performed in a sandy intertidal zone, their claim that this action is effective on firmer sediments suggests that this method is applicable to a rocky shoreline. Owens et al. (1992) also recommend medium pressure spot washing (at approximately 100 psi) to remove oil coated on solid surfaces, such as boulders and rock.

A variety of spray pressures and water temperatures may be used in flushing. Fingas (1991) differentiates among cold water deluge, cold water wash, and warm water wash. In cold water deluge, large volumes of water are pumped over a contaminated area. Cold water wash directs ambient sea water via fire hoses to oiled areas. Warm water wash involves spraying heated water (i.e., at approximately 60°C) at moderate pressure (i.e., at approximately 100 psi) onto contaminated areas. Using warm water is better for weathered oil that is what is expected in restoration situations. Restoration involving very high pressure spraying is rarely used now due to environmental and worker safety considerations. Hot water, high-pressure sprayers were employed, however, from both boat and shore following the *Exxon Valdez* discharge (Whitney, 1993).

Chemical restoration involves the use of surface washing agents that emulsify oil coated on solid surfaces. This makes it easier to contain and remove the oil (Fingas, 1991). Using a process known as "detergency," chemical restoration agents are sprayed onto the oiled surface a short period before flushing to loosen the oil. Although extensive laboratory testing was conducted on Exxon Corexit 9580 (which is on the U.S. EPA's National Contingency Plan approval list), it has never been used in an actual discharge incident (Lessard, 1992). This chemical was not approved for use in Alaska following the *Exxon Valdez* discharge.

Possible environmental impacts of this action include removal of organisms from the substrate, or recontaminating adjacent intertidal areas (Owens et al., 1992, see Chapter 3).

Flushing uses low- to medium-pressure water streams (i.e., less than 100 psi) to directly wash sediments and to release subsurface sediments through agitation. Heated (60°C) sea water is pumped through hoses, and applied by workers on the beach. Water used in flushing operations may be heated or ambient, but very hot water may injure biota that have survived oiling. Flushing is begun at the top of the oiled area during low tide, and continued downshore toward the water. Containment booms or sorbent sweeps are placed in the water to collect the freed contaminants. Skimmers or vacuum units are then used to recover the oil. This action requires at least one boat with a portable skimmer to collect oil washed into the water and held in containment booms. An additional boat equipped with a pump to deliver the water to the crew on shore may also be used, although pumping actions may also be performed from shore. The size of the crew will vary depending on the degree of contamination and other conditions.

Flushing is moderately reliable. Flushing will likely clear off some of the contaminants clinging to rock faces. However, some deep stains may remain.

Availability of Services, Materials and Equipment

The services required should be available from a number of discharge cleanup companies and cooperatives nationwide. Containment booms and sorbent sweeps are the principal materials required in the flushing operations, which are readily available in coastal areas. Exxon Corexit 9580 is available from the manufacturer in Texas. All equipment should be available in all coastal regions. No complex or unusual equipment is required for this restoration action. Most discharge cleanup companies and discharge cooperatives have experts in-house who are qualified to perform or oversee this action.

Constraints

This action will be constrained if the contaminated shoreline is in a high wave energy environment since crews will not be able to operate from boats and because oil will escape over containment booms. Further, this method is not feasible for shorelines with limited access or without suitable areas for short- or medium-term storage of recovered oil.

Future Restoration Actions

There is a risk of reoiling the shoreline with contaminants freed by the flushing process. If the containment system fails, previously cleaned or unoiled areas may need additional restoration.

2.2.6.1.3.5 Bioremediation

Bioremediation involves the use of fertilizers, surfactants, and/or bacteria to increase the populations of hydrocarbon-degrading microorganisms (Hoff, 1992). Specifically, bioremediation in the intertidal zone may be accomplished by seeding a shoreline with hydrocarbon-degrading microbe, and/or adding nitrogen- and phosphorus-containing fertilizers to enhance degradation. Fertilizers that may be applied can be of three types, soluble inorganic (e.g., agricultural fertilizers), oleophilic (i.e., chemically "sticky") nutrient formulations, or slow-release (i.e., granular) formulations (Hoff, 1992). Microorganisms that exist on shorelines require nitrogen and phosphorus to metabolize the carbon in oil. When the supply of nitrogen and phosphorus is depleted the degradation rate of oil declines (Owens et al., 1992). An increased level of nitrogen and phosphorus may stimulate the microbe population, thereby maintaining a high rate of hydrocarbon degradation. Also, limitation by oxygen and/or temperature may be important.

Oleophilic (literally "oil-loving") agents adhere to oil and increase the surface area of oil droplets exposed to microbes. In addition, the oleophilic agent discussed below, Inipol EAP 22, contains approximately 10 percent surfactants, which may also increase oil breakdown through dispersion (Hoff, 1992).

The use of bioremediation in restoration efforts is discussed in several recent sources including Hoff (1992), Pritchard and Costa (1991), Greene (1991), Jones and Greenfield (1991), Lee and Levy (1991), Chianelli et al. (1991), Glaser et al. (1991), and the U.S. EPA (1990). Although most of these studies were largely conducted following the *Exxon Valdez* discharge in the Prince William Sound, Alaska, the results of studies should apply more generally to restoration efforts in other marine and estuarine habitats. An early bioremediation effort restoring subsurface soils is described in Minugh et al. (1983) and early field experimentation is described in Tramier and Sirvins (1983).

Minugh et al. (1983) report the results of early field experience in bioremediation in a restoration effort involving subsurface soil contamination following the release of gasoline and diesel fuel from a bulk storage facility. In this test, nutrients and diffused air were pumped into contaminated silty soils. Over a nine-month period, 360 pounds of oxygen were added per day, along with 6,000 pounds of ammonium chloride and 3,000 pounds of sodium phosphate.

Pritchard and Costa (1991) considered application strategies, logistical problems, commercial availability, and the need to deliver nutrients to both surface and subsurface sediments in selecting fertilizers for the Alaska Oil Spill Bioremediation Project. The granular fertilizer Customblen was selected for subsurface soils and was spread using a mechanical seed spreader at a concentration of 0.20 lbs/m^2. Inipol EAP 22 was chosen for surface oil since it was the only commercially available oleophilic fertilizer that could meet site-specific requirements relating to ability of the nutrients to remain at the site of microbial activity for sustained periods, and could be produced quickly and in large quantities. Inipol was applied using backpack sprayers at a rate of 0.1 gallons/m^2.

Chianelli et al. (1991) describe the use of fertilizers in a field test of bioremediation efforts in response to the *Exxon Valdez* discharge. This effort consisted of adding nutrients (i.e., oleophilic fertilizers) only to oiled locations. The authors recommend an application rate for granular fertilizer (e.g., Customblen) of 0.07 lbs/m^2 when no surface oil is seen but subsurface oil is present. The application of granular fertilizer may be achieved using a hand spreader for subsurface oil. They further recommend liquid fertilizer (e.g., Inipol EAP 22) be applied onto surface coatings of oil at a rate of approximately 0.08 gallons/m^2.

Owens et al. (1992) recommend using nutrient-addition bioremediation as a "polishing action" following initial cleanup or when oiling is light and near the surface. They suggest the use of Inipol and Customblen as well. Their recommended implementation of this action is to deploy workers onto the contaminated shore with a small landing craft. Inipol would be applied using airless paint spraying equipment located on the boat, with workers using long hoses for full access to the shore. Inipol must be heated to 32°C. Customblen may be spread using a hand-cranked lawn spreader. They further recommend fertilizer application every two to four weeks to replace nutrients washed away by the tides. While these actions were developed following the *Exxon Valdez* discharge (where access from shore was limited), the actions described may be carried out entirely from shore.

Jones and Greenfield (1991) describe an intensive field effort in the bioremediation of terrestrial soil following a discharge of No. 6 fuel oil from a Florida power plant. This effort, conducted over 194 days, included site alterations to control drainage, the application of nutrients, water, and bacteria, and sediment tilling (to increase aeration). An area of approximately 4,089 m^2 was treated.

Hoff (1992) summarizes the use of bioremediation in several discharges by the Hazardous Materials Response and Assessment Division of the National Oceanic and Atmospheric Administration (NOAA). Hoff reports on the use of Inipol and Customblen following the *Exxon Valdez* discharge and also the application of Customblen alone following a pipeline break and discharge at the Exxon Bayway refinery in New Jersey. In this latter experiment, Customblen was placed in shallow trenches in an area with existing high levels of nutrients. Hoff also reports on microbe seeding efforts as well as open-water bioremediation. Following the collision of three Apex barges with a tanker in Galveston Bay in 1990, the microbial bioremediation product Alpha

BioSea was applied to oiled marsh in which mechanical recovery was determined to be infeasible. Application was made via high-pressure hose from a small boat. Following a well blowout in 1990 that oiled marsh grasses in the Seal Beach National Wildlife Refuge, the microbial product INOC 8162 was hand sprayed along with the commercial fertilizer MiracleGro 30-6-6. Finally, Hoff reports the experimental application of an unnamed microbial product from a Coast Guard vessel following the *Mega Borg* discharge and fire in the Gulf of Mexico. These case histories demonstrate the technical feasibility of a variety of actions. Effectiveness is evaluated in Chapter 3.

Bioremediation is fairly simple to conduct. In essence, it is very similar to fertilizing in landscape work with either a backpack sprayer (i.e., for liquids) or lawn or hand spreader (i.e., for granular nutrients). Items necessary for performing this activity are vehicles (i.e., for access, transportation, and storage of agent), workers, and backpack sprayers and/or fertilizer spreaders. If bioremediation is conducted from the sea, boats will be needed as well.

<u>Availability of Services, Materials and Equipment</u>

The availability of services should not be a problem. At this point, only a few people have a full understanding of this technology (Merski, 1992). Experts in the field seem eager to become involved in additional bioremediation efforts. As additional scientific work is published, expertise will spread. The equipment needed for the deployment of these fertilizing agents is identical to that used for common lawn care. Therefore, there should be no difficulty in obtaining the proper equipment.

<u>Constraints</u>

The operational constraints of bioremediation depend on conditions at the site. Typical operational constraints are related to access to shore and amount of wave energy. Waves that are too strong (and so remove the fertilizer) or too weak (and so too little flushing and oxygen replenishment) will render bioremediation less effective. (See Chapter 3 for more on effectiveness and success.)

Obtaining information on the availability and use of the bioremediation agents can be difficult and time-consuming due to the fact that bioremediation is an evolving technology. Standard guidelines for application are not consistently developed and documented. Developing an application plan for a specific situation may involve considerable communication with experts.

There appear to be few logistical constraints for applying bioremediation agents. In general, this technology is best adapted for light oiling of fine- to medium-grained beaches in moderate wave energy environments (where tidal action will disperse nutrients over an area without washing them away). The necessary equipment is mobile enough for access to many shorelines. Nutrients can also be sprayed or spread from boats or by shore-based crews.

The addition of nutrients may cause concern over eutrophication. This needs to be evaluated for the site being considered. Toxicity of the bioremediation agent must also be assessed.

2.2.6.2 Intertidal Cobble-Gravel Beaches

The restoration actions relevant for the restoration of cobble-gravel intertidal habitats include:

- Natural Recovery;
- Flushing;
- Sediment Washing;
- Sediment Agitation; and
- Bioremediation.

2.2.6.2.1 Oil Related Literature

The oil discharge-related literature used to evaluate technical feasibility of restoration actions in cobble-gravel intertidal habitats is summarized here. Anderson et al. (1983), Klokk et al. (1983), Lehr and Balen (1983), Owens et al. (1983), van Oudenhoven (1983), Jahns et al. (1991), Little and Little (1991), and Owens et al. (1992) discuss natural recovery following oil discharges in intertidal habitats. Anderson et al. (1983), Howard and Little (1987), and Owens et al. (1992) detail flushing in intertidal areas. Flushing following chemical restoration is discussed by the American Petroleum Institute (1991), Fingas (1991), and Owens et al. (1992). Richard Lessard of Exxon was also contacted and interviewed for this analysis. Sediment washing is described by Gumtz (1972), Morris et al. (1985), Bocard et al. (1987), and Huet et al. (1989). Sediment agitation in intertidal zones is discussed by Morris et al. (1985), Levine (1987), Miller (1987), Blaylock and Houghton (1989), and Owens et al. (1992). Robert Levine of Arco Marine was also contacted for further information on sediment agitation during this effort. Finally, numerous sources cover the developing practice of bioremediation. Minugh et al. (1983), Tramier and Sirvins (1983), the U.S. Environmental Protection Agency (1990), Chianelli et al. (1991), Glaser et al. (1991), Greene (1991), Jones and Greenfield (1991), Lee and Levy (1991), Pritchard and Costa (1991), and Owens et al. (1992) appear in the literature. Interviews were also conducted with relevant bioremediation experts, including Russell Chianelli and James Bragg of Exxon and Alain Drexler and Paul Benn of Elf-Aquitaine.

2.2.6.2.2 Non-oil Literature

Most of the literature on restoration in cobble-gravel intertidal habitats concerns the restoration of oil-related injury. Thus, non-oil related literature was not reviewed.

2.2.6.2.3 Technical Feasibility of Restoration Actions

Exhibit 2.11 summarizes the technical feasibility of the restoration actions for cobble-gravel intertidal habitats. Note that the findings of this exhibit apply to lacustrine cobble-gravel shore habitats, subsequently presented in Section 2.2.8. Each action should include a monitoring program.

2.2.6.2.3.1 Natural Recovery

Monitoring of natural recovery is a technically feasible option. See Chapter 3 for a discussion of recovery.

2.2.6.2.3.2 Flushing

The use of low-pressure flushing to remove oil adhering to surface materials in sand or gravel beaches and flush it back into the water is discussed in the response literature by Owens et al. (1992) and Howard and Little (1987). Its use has not been documented as a restoration action, but it is technically feasible as a restoration action. Howard and Little discuss the results of field tests of ambient seawater flushing on fine-grained intertidal sands. Water was hosed at a rate of two liters per second toward the lower end of test plots. A side-to-side motion was used to loosen contaminants. Refloated oil was contained using booms deployed in the water, and the oil was collected from the water surface using hand scoops and placed into an oil/water separator. Howard and Little found this action to be very effective in recovering oil from fine sandy sediments. On average, 85 percent of applied fuel oil was recovered. They note that this action works best on relatively firm sediments, but make the important observation that it may be unsuccessful on very coarse sands and gravel due to erosion and the mixing of sediments and oil. Greater permeability of sediments or depth of the water table may impede flushing. Since this action relies on raising the water table, oil and sediment may become mixed when this does not occur.

Owens et al. (1992) recommend the flushing action for fine- and coarse-grained gravel shorelines. The larger sediments on cobble-gravel beaches present an appropriate habitat for flushing. In their recommended action, oil is washed off of sediments and flushed downshore for collection from the water surface. They indicate that highly weathered oil is likely to be somewhat resistant to this action, but that it is ideal for mobile oil and oil coating surface sediments lightly.

Exhibit 2.11 Overview of Technical Feasibility of Cobble Gravel Shore Restoration

	State of Feasibility	Availability of Services and Materials	Key Constraints	Future Restoration Efforts	Legal and Administrative Factors
Natural Recovery	Generally feasible	Generally available	Little constraint	May require cleaning of areas contaminated by freed oil	Coordination of monitoring activities
Flushing	Generally feasible	Generally available in coastal areas Chemical restoration agents available	Boats must be able to access site Removal of organisms Requires temporary storage site for recovered oil May drive oil deeper into sediments	Possible reoiling if freed oil escapes containment system May drive oil deeper into sediments requiring further action	Permits may be difficult to obtain for use of chemical agents
Sediment Washing	Generally feasible	Purpose-built equipment not widely available, but can be assembled from available components	Qualified engineer recommended for washer assembly Backshore site required Lethal to organisms	Possible if recolonization of sediments does not occur	None expected

Exhibit 2.11 (continued)

	State of Feasibility	Availability of Services and Materials	Key Constraints	Future Restoration Efforts	Legal and Administrative Factors
Sediment Agitation	Technique has been developed	"Muck Monster" technology is patented; must work through Arco Marine Equipment rental may be difficult	Qualified engineer needed to assemble equipment Access to shore by heavy equipment needed Worker safety issues	None expected	Permits required
Bioremediation	Technique is currently being developed, most successful in case of *Exxon Valdez*	Services and equipment generally available	Few people have strong bioremediation expertise in estuarine and marine systems Work crew access to shore is critical Possible eutrophication effects	None expected	Thorough documentation of efforts Permits required

The Corpus Christi Area Oil Spill Control Association (CCAOSCA) utilizes a low-pressure flushing action in most of its discharge responses (Christian, 1991). They have found this to be the least expensive action applicable to a number of habitats, including sandy beaches and erosional scarps. Factors complicating flushing efficiency and cost include shore type and contaminant type. Rubble shores require the most effort of the shorelines to which the CCAOSCA must respond and thicker oil may require repeated flushing to be cleaned.

Potential impacts from flushing include removal or mortality of organisms, habitat disruption, and oiling of clean sediments by freed oil (Owens et al., 1992; see Chapter 3). Flushing actions (including the use of chemical restoration) are described for rocky intertidal habitats in Section 2.2.6.1.3.4. Issues related to technical feasibility in cobble-gravel intertidal habitats are similar to those described in that Section.

2.2.6.2.3.3 Sediment Washing

Bulk oil deposited on gravel, cobble, or sandy beaches is generally removed during cleanup operations either through natural processes or the use of methods such as flushing, vacuum pumping, etc. Once bulk oil is removed from beaches, a residual amount can be found deposited in the substrate. Thus, restoration in these habitats may focus on remediating the contaminated beach materials. Several methods for removing residual contamination have been demonstrated. These include washing the material on site, agitating and flushing the upper layers of material, or depositing the material to the surf zone for natural washing (Johnson and Pastorok, 1985). For this effort, sediment washing involves the containment and removal of contaminants by collecting, washing on-site, and re-distributing beach material.

Several sources discuss the use of sediment washing in field experimentation (Gumtz, 1972; Bocard et al., 1987, Huet et al., 1989; and Morris et al., 1985). Gumtz (1972) details the development and field testing of a mobile beach cleaning (sediment washing) device constructed for the U.S. Environmental Protection Agency. This machine was constructed on a 40-foot trailer and is comprised of a froth flotation machine with a belt feeder for sand, a submersible water pump, an air supercharger, and a diesel electricity generator. After extensive field testing, Gumtz concluded that this mobile cleaner could operate at a capacity of 30 tons per hour.

Bocard et al. (1987) describe tests of a prototype mobile sand-washing plant designed for deployment in the event of oil discharges. Huet et al. (1989) describe the use of such a sand-washing device for cleaning oil-contaminated pebbles. With this technology, contaminated gravel is stripped from the beach and placed into a loading funnel from which it drops into a rotating washing cylinder (i.e., drum scrubber). The gravel is washed with warm water to which a cleaning agent has been added. The gravel is then transferred to a hydro-cyclone to separate it from the wash water. Decanting tanks are used to separate oil from the wash water. After washing, the gravel can be re-deployed on the beach. The throughput of the washing apparatus was demonstrated to be approximately 18 metric tons per hour. Soil with an initial oil content of roughly 5 to 10 percent had an average residual oil content of 0.2 percent after cleaning (for moderately weathered oil).

Morris et al. (1985) report on tests of a device similar to the one described by Brocard et al. (1987). The equipment used was essentially a standard sand and gravel washing plant typically found in quarries, modified to handle a courser feed with an added device to separate the oil from the washing water. The wash water had kerosene added to expedite cleaning. A device was tested that had a throughput of 14 metric tons of beach material per hour. Beach material with an initial oil content of two to six percent was washed to a final product containing 0.15 percent oil.

Anderson et al. (1983) describe a modified use of sediment washing (actually, relocation of oiled sediments to the surf zone). They recommend such an action for low priority, low amenity beaches.

Owens et al. (1992) indicate that sediment washing units may be specially-constructed "drum types or adapted commercially-available equipment, such as portable or truck mounted cement mixers." Further, they indicate that the solutions used for washing may include either water (hot or cold) and/or dispersants or beach cleaning agents. They note that cleaning time is related to the oil type, degree of weathering, loading, and temperature of wash water. Higher wash water temperatures and the use of cleaning agents are likely to decrease wash time. They recommend that wash cycles should begin at 10 to 15 minutes and adjusted to reflect the efficacy of the sediment washing process.

Sediment washing is best suited for use on moderate to heavily-oiled shorelines, especially in sheltered, low energy areas. It is best if the shore is comprised of medium-grained sediments.

Sediment washing will injure organisms (as discussed in Chapter 3). In addition, manual removal of sediment may cause oil to be mixed into the substrate by personnel and vehicle traffic at the site. Substrate removal on cobble shorelines may cause erosion or flooding of backshore areas, erosion of adjacent shorelines, and depletion of offshore sediment deposits. Owens et al. (1992) list some net loss of material and the temporary destabilization of the beach as the potential impacts of sediment washing.

A potential restoration action for these intertidal habitats is a method employing a sand-washing action such as those described above. Sediment washing is conceptually a fairly simple operation. Oiled sediments are removed manually (e.g., with a shovel) or mechanically (e.g., with a front loader), transported to a backshore area, and run through the washing equipment. Washing may be performed with or without detergents or dispersants, depending on the extent of oiling, regulatory requirements, etc. After washing, cleaned sediments are redeployed on the beach (ideally the identical spot from which they were removed). Wash water and recovered oil may be separated, and the wash water reused. Decanted oil is then stored for disposal or transport to a recycling facility.

Availability of Services, Materials and Equipment

The detergents or dispersants used with the sediment washer should be readily available commercially. While "purpose-built" washers are not common, a sediment washer can be assembled from readily-available equipment. Mechanical removal devices (e.g., front-end loaders, backhoes, bulldozers, manual labor, hand tools), conveyors, and cement mixers should be readily available in all regions of the United States.

A qualified civil engineer with road or construction site preparation experience is likely to be able to assemble a beach cleaning apparatus using components from the excavation industry. This assumes the engineer has access to the relevant literature describing sediment washing devices.

Constraints

This procedure requires access to oiled beaches for crews and equipment (e.g., front end loaders, etc.). This method also requires sufficient room in backshore areas for the sediment washer and other equipment. After they have been washed, the sediments should be returned to the exact location from which they were found.

Future Restoration Actions

Future restoration actions may be required if recolonization of sediments by organisms does not occur naturally after the washing process. It may be necessary to begin the recolonization process by transplanting some sediment-dwelling organisms to the cleaned sediments.

2.2.6.2.3.4 Sediment Agitation

Sediment agitation is performed by turning oiled sediments to break up oiled layers and enhance natural degradation processes (e.g., physical, microbial, and photochemical) (Owens et al., 1992). Sediment agitation also allows access to and treatment of subsurface oils.

The agitation of sediments for the removal of stranded oil and emulsion is discussed by Morris et al. (1985), Levine (1987), Miller (1987), Blaylock and Houghton (1989), and Owens et al. (1992). Owens et al. (1992) describe the process, which they call sediment tilling. This involves using a tractor fitted with tines or ripper blades to till sediments near the surface in oiled areas. Morris et al. (1985) report field experiments of various sediment agitation actions for removing water-in-oil emulsions from firm sandy beaches. A variety of equipment configurations were used, including standard vehicle-mounted snowplows, tracked bulldozers, diggers fitted with rubber blades, tractor-mounted scrapers, and front-loader tractors. They found rubber-bladed equipment attached to a front-end loader the best-suited configuration for firm, sandy sediments. Manual tilling is also an option for smaller areas, with the advantage of causing less operational impact.

Levine (1987) and Miller (1987) describe the use of a beach agitation device in the cleanup of the *Arco Anchorage* discharge in Port Angeles Harbor, Washington. A beach agitation device was used in conjunction with high-pressure flushing and vacuum pumping to remove subsurface oil and restore a beach composed of sand, gravel, and cobble.

Arco Marine's patent for the Muck Monster includes modifications to the basic design described in Levine (1987) to replace the bulldozers with log skidders (Levine, 1992). Log skidders are similar to bull dozers, but have large, balloon-type wheels rather than tracks. Although the bulldozers used in the *Arco Anchorage* cleanup used wider-than-conventional tracks, the design for the Muck Monster was modified to use a vehicle with tires to minimize ecological impacts by reducing the load delivered to the sediments and to provide higher ground clearance and greater mobility.

A potential impact from sediment agitation is the mixing of oil deeper into sediments (Owens et al., 1992). Even when beach cleaning machines result in few physical impacts to the beach structure, they may clean only the surface of the beach (Johnson and Pastorok, 1985).

The actions utilized for sediment agitation are assumed to be similar to those developed by Arco Marine, Inc. for the cleanup of the *Arco Anchorage* discharge (Levine, 1987). These actions have been patented by Arco Marine, so it would be necessary for any discharge responder to contact Arco Marine for guidance before using a Muck Monster III for cleanup. Arco Marine assisted in the cleanup of Huntington Beach, California, following the *American Trader* discharge, and did not seek any compensation for its activities beyond seeking reimbursement for cellular phone usage (Levine, 1992).

Evaluation of potential impacts on biota is in Chapter 3.

<u>Availability of Services, Materials, and Equipment</u>

Since the Muck Monster restoration method is patented by Arco Marine, Inc., the trustees involved in restoration must contact Arco Marine to use this method. Although this is the case, there are no anticipated impacts to technical feasibility from this requirement. In cooperation with any discharge response effort, Arco Marine will send personnel to a discharge site at little or no cost (Levine, 1992).

The materials used in carrying out this restoration action (e.g., sorbents, sweeps, etc.) should be readily available in all coastal areas of the United States.

In some cases, there may be some difficulty finding equipment to rent. The bulldozers used in *Arco Anchorage* restoration were effectively destroyed, bearings were degreased, and the generator and electrical system was damaged. An equipment supplier aware that heavy equipment is to be used in salt water may be hesitant to rent it out. Furthermore, log skidders equipment found in timber areas may be difficult to find in some regions (Levine, 1992).

Levine (1992) recommends that a qualified engineer (e.g., from the equipment manufacturer, such as John Deere) be on scene to assist in assembly of required equipment.

Constraints

No construction constraints are expected. The constraints related to the assembly of the Muck Monster are related to expertise and the availability of equipment. Further operational constraints are discussed below.

In cases where access to shoreline is possible using landing craft only, and where tides are high, this restoration method may not be feasible since equipment would need to be moved nightly (Levine, 1992).

Levine (1992) noted that there were additional concerns for occupational health and safety at the Muck Monster job site since workers must work in water. Cold water may increase rate of fatigue. Workers must also wear life jackets and other OSHA-required gear. During the *Arco Anchorage* discharge, workers occasionally fell into the water. There was additional risk to workers laboring near moving heavy machinery.

Finally, the bulldozer operator must pay strict attention to the slope of the shoreline since the Muck Monster is operating in water. Sudden dropoffs and submerged objects present additional hazards.

This action should be limited to mid- and upper-intertidal zones to limit the impact on biota. Further discussion of impacts is in Chapter 3.

Future Restoration Actions

While long-term monitoring may be recommended, additional restoration efforts are not needed. The state of Washington's monitoring requirement was reduced since cleaning was found highly effective (Levine, 1992). Blaylock and Houghton (1989) report the results of a 30-month infaunal sampling project that showed a statistically significant increase in average biomass, density, and species diversity in areas oiled heavily in the *Arco Anchorage* discharge. Similar increases were not shown in unoiled control areas. This indicates that this restoration action is effective without continuing restoration efforts.

2.2.6.2.3.5 Bioremediation

Bioremediation is described in detail in Section 2.2.6.1.3.5. The details and considerations presented in that section also apply to cobble-gravel intertidal habitats.

2.2.6.3 Intertidal Sand Beaches

A review of restoration-related literature indicates that the following restoration actions are applicable to sand intertidal habitats:

- Natural Recovery;
- Flushing;
- Sediment Washing;
- Sediment Agitation;
- Bioremediation; and
- Incineration.

This section describes each of the relevant restoration actions and their technical feasibility within the sand beach intertidal habitat.

2.2.6.3.1 Oil Related Literature

Oil related literature for flushing, sediment washing, sediment agitation, and bioremediation is discussed in Section 2.2.6.1.1. Incineration of contaminated sand is discussed by van Oudenhoven (1983) and Eidam et al. (1975).

2.2.6.3.2 Non-oil Related Literature

For the most part, the literature encountered in this effort dealt with the contamination of sand intertidal habitats by oil. However, data provided by Garbaciak (1992) related to the incineration and disposal of sand contaminated by toxic substances. Sand dune restoration in general is discussed by Knudson (1980) and Salmon et al. (1982).

2.2.6.3.3 Technical Feasibility of Restoration Actions

Since the restoration methods for sand intertidal habitats are similar to those for other intertidal habitats, the following sections heavily reference these other sections and do not repeat the findings. The exception to this is the discussion of incineration, which is appropriate for sand sediments only. Exhibit 2.12 summarizes the technical feasibility of restoration actions. Note the findings in this exhibit apply to riverine and lacustrine sandy shore habitats, discussed in Section 2.2.8.3. Each action should include a monitoring program.

2.2.6.3.3.1 Natural Recovery

Monitoring natural recovery is technically feasible. See Chapter 3 for a discussion of recovery.

2.2.6.3.3.2 Flushing

This action is discussed in detail in Section 2.2.6.1.3.2.

2.2.6.3.3.3 Sediment Washing

Sediment washing in sand intertidal habitats is essentially the same as in cobble-gravel environments. Therefore, see Section 2.2.6.2.3.3. for a discussion of this method.

2.2.6.3.3.4 Sediment Agitation

Sediment agitation is similar in sand and cobble-gravel intertidal habitats. See Section 2.2.6.2.3.4. for a detailed overview of this method.

2.2.6.3.3.5 Bioremediation

Refer to Section 2.2.6.1.3.5. for a detailed description of bioremediation.

2.2.6.3.3.6 Incineration

While incineration destroys remaining biota in the sediments, it is a potential action for restoring services of a sand beach. Most of the literature related to incineration or burning in oil discharge response or restoration discusses the burning of oil slicks at sea or in broken ice. Owens et al. (1992), Buist (1987), Smith and Diaz (1987), Whittaker (1987), Tennyson (1991), Allen (1991), and Evans et al. (1991) discuss burning of oil in these habitats. These are clearly response actions and not restoration and will not be discussed further.

However, there is little discussion in the literature of the incineration of oiled sediments in the intertidal zone, which might be considered a restoration action. Following the contamination of sand sediments in Qatar, several incineration disposal methods were examined for the disposal of contaminated sand (van Oudenhoven, 1983). Combustion was attempted using oil alone, gasoline, kerosene, and a combination of kerosene and driftwood. Following the *Tamano* discharge in the Casco Bay in Maine, incineration and the recycling of sand was considered (Eidam et al., 1975). No appropriate incinerator was found in the New England area which could handle the sand.

Exhibit 2.12 Overview of technical feasibility of sand shore restoration.

	State of Feasibility	Availability of Services and Materials	Key Constraints	Future Restoration Efforts	Legal and Administrative Factors
Natural Recovery	Generally feasible	Generally available	Little constraint	May require cleaning of areas contaminated by freed oil	Coordination of monitoring activities
Flushing	Generally feasible	Generally available in coastal areas Chemical restoration agents available	Boats must be able to access site Requires temporary storage site for recovered oil Removal of organisms	Possible reoiling if freed oil escapes containment system	Permits may be difficult to obtain for chemical restoration
Sediment Washing	Generally feasible for areas of low ecological sensitivity	Purpose-built equipment not widely available, but can be assembled from available components	Qualified engineer recommended for washer assembly Backshore site required Lethal to organisms	Possible if recolonization of sediments does not occur	None expected

Exhibit 2.12 (continued)

	State of Feasibility	Availability of Services and Materials	Key Constraints	Future Restoration Efforts	Legal and Administrative Factors
Sediment Agitation	Technique has been developed	"Muck Monster" technology is patented; must work through Arco Marine Equipment rental may be difficult	Qualified engineer needed to assemble equipment Access to shoreline by heavy equipment needed Worker safety issues	None expected	Permits required
Bioremediation	Technique is currently being developed	Services and equipment generally available	Few people have strong bioremediation expertise in estuarine and marine systems Work crew access to shore is critical Possible eutrophication effects	None expected	Thorough documentation of efforts Permits required
Incineration	Technology has been developed	Mobile incinerators may not be available	Equipment must be able to access site Lethal to organisms Smoke generated must not impact wildlife or humans	Sediment replacement may be required	Permits likely to be required
Removal and Replacement	Generally feasible	Upland disposal site required	Experts must verify removal is required Removal of organisms Sand causeway to site may reduce impacts	Possible if recolonization of sediments does not occur	Likely to be required

In the event that incineration is used to burn contaminated intertidal sand, if available, some type of mobile incinerator could be used. Such an incinerator would be placed in a backshore area adjacent to the area of contamination. Contaminated sediments would be removed manually or by using mechanical equipment. Whether or not mechanical equipment is used would depend on whether the sediments can support their weight and on environmental sensitivity. Removed sediments would then be transported to the backshore area. Debris would be separated and the sand would be fed into the incinerator to burn the oil.

Availability of Services, Materials and Equipment

Services and materials needed for incineration are available in selected locations. The availability of mobile incinerators, however, is an issue that may affect the technical feasibility of incineration. As Eidam et al. (1975) found, incinerators able to handle sand could not be found in New England. It is possible that portable incinerators may not be available in all regions of the country.

Constraints

The use of incineration in restoration assumes that mechanical equipment can be brought onto the beach for sand removal in some cases. If sand cannot support heavy equipment, or if organisms in the area are sensitive, it may be necessary to utilize manual removal of sediments.

Further, it is assumed that there is adequate room in backshore areas for an incinerator. Finally, the smoke generated by incinerator must not adversely affect workers, wildlife, or nearby residents.

Future Restoration Actions

In some cases, removed sediments will be replaced. The removal of sediments from some areas may lead to accelerated erosion. Sediment replacement will naturally increase effort and cost.

2.2.6.4 Intertidal Mud Flats

Mud flats are compacted, fine-grained sediments often backed by sandy beaches or marshes. Mud flat intertidal habitats occur in areas in which general circulation results in sediment deposition (Johnson and Pastorok, 1985).

Unlike the soils found in sand and cobble-gravel intertidal habitats, few technologies have been effectively demonstrated for restoring mud. Sediment washing, for example, requires larger-grained beach material. Flushing is unlikely to be feasible in fluid muds due to sediment-oil mixing (Howard and Little, 1987). Some logistical barriers also exist for using many of the restoration technologies requiring heavy equipment on site. Mud sediments cannot physically support heavy machinery and, thus, access from land may not be possible.

An assessment of restoration literature indicates that the following restoration actions may be relevant to mud flat intertidal habitats:

- Natural Recovery;
- Sediment Removal and Replacement; and
- Bioremediation.

This section discusses the technical feasibility of each restoration action within the mud flat intertidal habitat.

2.2.6.4.1 Oil Related Literature

The literature covering restoration of mud flats deals mostly with oil discharge contamination. Several oil discharge related documents were reviewed. Johnson and Pastorok (1985), van Oudenhoven (1983), and Lehr and Balen (1983) discuss removal and replacement efforts in mud flat discharge remediation. Finally, the same bioremediation sources listed above for other intertidal habitats also apply to mud flat bioremediation.

2.2.6.4.2 Non-oil Related Literature

No literature discussing restoration of mud flats in a non-oil context were identified.

2.2.6.4.3 Technical Feasibility of Restoration Actions

The technical feasibility of each restoration action in mud flat intertidal habitats is discussed below and summarized in Exhibit 2.13. Note that these actions also apply to riverine and lacustrine silt-mud shores, subsequently presented in Section 2.2.8.4. Each action should include a monitoring program.

2.2.6.4.3.1 Natural Recovery

Monitoring of natural recovery is a technically feasible action. See Chapter 3 for a discussion of recovery.

Exhibit 2.13 Overview of technical feasibility of mud flat restoration.

	State of Feasibility	Availability of Services and Materials	Key Constraints	Future Restoration Efforts	Legal and Administrative Factors
Natural Recovery	Generally feasible	Generally available	Little constraint	May require cleaning of areas contaminated by freed oil	Coordination of monitoring available
Sediment Removal and Replacement	Generally feasible	Upland disposal site required	Experts must verify removal is required Removal of organisms Sand causeway to site may reduce impacts	Possible if recolonization of sediments does not occur	Permits likely to be required
Bioremediation	Technique is currently being developed	Services and equipment generally available	Few people have strong bioremediation expertise Work crew access to shore is critical Possible eutrophication effects	None expected	Thorough documentation of efforts Permits required

2.2.6.4.3.2 Sediment Removal/Replacement

Johnson and Pastorok (1985) indicate that manual sediment removal is a viable action for the cleanup of oil discharges in tidal flat habitats. However, residual oil contamination may become mixed into the sediments (Johnson and Pastorok, 1985). This will leave only some type of sediment cleaning or replacement as feasible actions. Since field applications of the sediment washing technologies described for cobble-gravel and sandy intertidal habitats above (Sections 2.2.6.2 and 2.2.6.3, respectively) have not been applied to the finer sediments found in mud flats, the only reasonable manual removal restoration action for the mud flat intertidal habitat is the mechanical removal, disposal, and replacement of contaminated sediments. Van Oudenhoven (1983) reviews restoration efforts in mud flats. He notes that oil on mud flats that was not removed remained there nearly three years after the discharge came ashore. Furthermore, he recommends the use of manual labor on mud flats to minimize ecological injury. A action used in the response involved construction of temporary sand causeways on the flats, manual scraping of oil, transportation of contaminated soil by wheelbarrow to front-end loaders located on the causeway, and placement of removed mud in dump trucks in backshore areas.

Removal and replacement of mud sediments involves removing contaminated soil, loading and transporting it for disposal, and obtaining and deploying replacement soil in its place. This method should use a removal action similar to that described in van Oudenhoven (1983). Work crews remove contaminated mud manually, and transport it (e.g., using a wheelbarrow) to a backshore area. Contaminated soil is piled on site in the backshore area to await loading onto a dump truck for transportation to a disposal facility. Soils containing non-hazardous contaminants will likely not need treatment or stabilization prior to disposal in an upland landfill. Replacement soil is then trucked to the backshore area, transported manually onto the restoration site, and manually spread by workers to a rough finish grade.

Availability of Services, Materials, and Equipment

The services required for this restoration action should be readily available in all areas of the country. Necessary services include basic landscaping labor and trucking. At this point, upland disposal is generally available within a reasonable distance in all regions of the country. Should some type of toxic or hazardous contaminant be involved, however, disposal alternatives will be limited since contaminated soils will need to be transported to a qualified facility meeting Resource Conservation and Recovery Act (RCRA) standards. Cost and logistical problems will increase in these cases.

No restraints to technical feasibility are expected from factors related to materials. The only material requirement for this action is the soil needed for replacing the soil removed. Suitable soil should be available nationwide. Finally, no exceptional equipment needs are anticipated for this restoration action.

Experts qualified to assess whether the drastic measures of removal and replacement should be performed should be consulted before this action is used. Since heavy mortalities to sediment-dwelling organisms are likely in these ecologically-important areas, it should be determined that removal and replacement will have a net benefit to the mud flat habitat.

Constraints

The construction of a sand causeway as described in van Oudenhoven (1983) may be recommended. While this is an additional task in the restoration process, it does not present a significant increase in the level of effort required. Care must be taken when operating in a mud flat habitat to minimize contact with mud sediments. This is recommended for equipment, machinery, and work crews. A sand causeway may be constructed to establish a regular path to work areas and limit traffic on other areas of the mud flat. If care is not exercised, traffic or removal operations may mix oil with deeper sediments, exacerbating contamination.

If tides are a significant factor, evacuation operations must be coordinated with the tidal cycle. This may decrease efficiency of the operations.

Future Restoration Actions

Additional restoration may be required if sediment-dwelling organisms are severely affected by removal operations. If high levels of mortality occur and recolonization is inhibited, some type of transplantation of organisms may be considered.

2.2.6.4.3.3 Bioremediation

This restoration action is discussed in detail in Section 2.2.6.1.3.5.

2.2.7 Estuarine and Marine Subtidal Habitats

2.2.7.1 Subtidal Rock Bottoms

Subtidal rock bottom habitats include deep hard bottom environments that encompass solid, hard substrates as well as reefs composed of many individual rocks (Johnson and Pastorok, 1985). Typically in subtidal rock bottom habitats there is little or no sedimentation activity and high wave/current energy input, yielding good natural cleaning characteristics.

Restoration in subtidal rock bottom habitats in the event of oil contamination has historically consisted of minimal direct action, with primary reliance on the natural recovery process for restoration. Only one restoration action is feasible for habitat restoration:

- Natural Recovery.

The following sections summarize the available literature pertaining to restoration in subtidal rock bottom habitats.

2.2.7.1.1 Oil Related Literature

Available literature specific to the restoration of rocky subtidal habitats contaminated from an oil discharge suggests that habitat restoration can be accomplished simply by ensuring the removal of all contaminants. For many habitats this is typically not the case and additional restoration actions are generally performed to enhance the recovery process. As discussed in a report prepared for the American Petroleum Institute (Johnson and Pastorok, 1985), oil that reaches rocky bottom habitats is commonly abandoned to the natural forces of dispersal and weathering. Other alternatives for response are also presented in this report for consideration (e.g., vacuum pumping, sorption, chemical dispersal), yet the feasibility of these actions in underwater habitats is largely undetermined.

2.2.7.1.2 Non-oil Related Literature

The restoration of subtidal rock bottom habitats due to non-oil related injury is not well documented. Non-oil related injury would typically include incidents such as contamination from toxic releases other than oil as well as physical disturbances from storm activity. There is little documentation in the literature of direct restoration activities performed in rock bottom habitats related to these types of injuries.

2.2.7.1.3 Technical Feasibility of Restoration Actions

Exhibit 2.14 presents an overview of the state of technical feasibility for the restoration action appropriate to subtidal rock bottom habitats. Monitoring of natural recovery is the only technically feasible action. See Chapter 3 for a discussion of recovery.

Exhibit 2.14 Overview of technical feasibility of subtidal estuarine and marine rock bottom restoration.

	State of Feasibility	**Availability of Services and Materials**	**Key Constraints**	**Future Restoration Effects**	**Legal and Administrative Factors**
Natural Recovery	Generally feasible	Generally available	Little constraint	Unlikely that additional activity be required	Coordination of monitoring activities

2.2.7.2 Subtidal Cobble-Gravel, Sand, and Silt-Mud Bottoms

With the exclusion of rock bottom areas, subtidal bottom habitats in the estuarine and marine environment have sediments that can be classified as cobble-gravel, sand, or silt-mud. Due to the similarity of restoration actions available for each of these subtidal bottom types, these alternatives are presented as one discussion, with specific attention to those applications distinct among habitats. The following restoration actions were found to be applicable to cobble-gravel, sand, and silt-mud bottom habitats:

- Natural Recovery;
- Dredging/Material Removal; and
- Sediment Containment/Replacement.

The following sections summarize the available literature on subtidal bottom restoration and discuss the technical feasibility of each restoration action.

2.2.7.2.1 Oil Related Literature

In the event of an oil discharge, bottom sediment can become contaminated by sinking of oil adhering to particulates. The available literature on oil related restoration actions for subtidal bottom habitats has focused primarily on cleanup actions. For sediment-dominated subtidal bottom habitats oil discharge cleanup actions may be used in restoration. Two studies sponsored by the American Petroleum Institute assess cleanup and restoration actions associated with oil discharge conditions. Johnson and Pastorok (1985) present an evaluation of oil discharge cleanup actions for several estuarine and marine habitat types, including subtidal bottoms. To clean oil-contaminated bottom sediments this report evaluated sediment removal. The second more recent report (API, 1991) focuses on the restoration of oil contaminated habitats and evaluates restoration alternatives applicable for subtidal habitats (i.e., sediment removal for contaminated sediments).

2.2.7.2.2 Non-oil Related Literature

Non-oil related impacts to subtidal bottom habitats typically involve the contamination of bottom sediments from toxic pollutants other than oil (e.g., PCBs, metals, etc.). The available literature on the restoration of non-oil related injury to subtidal habitats is sufficiently documented by case studies and reports that detail appropriate methods and actions to restore the contaminated bottom habitats. These reports identify sediment management practices geared toward the restoration of contaminated subtidal areas that have varying sediment characteristics.

The following literature sources are examples of studies that evaluate this information for estuarine and marine environments:

- Phillips and Malek (1987) review alternative dredging and disposal practices proposed for the restoration of contaminated sediment in Commencement Bay, Washington. Factors discussed include equipment selection and methods and the preferred dredging methods for various classes of contaminants;

- Palermo and Pankow (1988) describe appropriate dredging equipment, actions and controls for removal of contaminated sediments from an estuary. The major factors discussed include: dredging requirements, factors in selection of equipment, methodologies used to select the most appropriate equipment, operational procedures for contaminant cleanup, and control measures for resuspended sediment;

- Averett and Palermo (1989) review conceptual dredging and disposal alternatives for a contaminated estuary. The technical feasibility of alterative disposal actions such as upland and nearshore disposal is discussed, including factors such as sediment characteristics, site availability, and capacity;

- National Research Council (1989) provides a comprehensive review of the strategies surrounding the disposal of contaminated sediments, including an assessment of contamination, mobilization and resuspension, and remediation technologies;

- Palermo et al. (1989) present a strategy for the evaluation of major disposal alternatives for the disposal of contaminated sediment. This study also evaluates the dredging equipment appropriate for selected disposal alternatives, which include confined upland, confined nearshore, and contained aquatic disposal;

- Averett et al. (1990) identify feasible technologies to remove contaminated sediment from the Great Lakes. This evaluation includes a review of alternatives for the removal of contaminated sediments including subsequent transport, treatment, containment, or disposal, and those for non-removal alternatives, such as *in situ* treatment or containment of the contaminated sediment;

- Cullinane et al. (1990) provide a thorough review of alternative technologies and strategies for the removal, control, treatment, and/or disposal of contaminated dredged material. This review includes applications to and site scenarios for ocean, estuarine, and inland disposal; and

- Marcus (1991) reviews practices employed for the management of contaminated sediments in aquatic environments. The author explores current sediment regulation and alternatives for remediation.

Each of these studies focuses on the available actions for removal of contaminated sediment as well as subsequent disposal and/or treatment of the dredged material. It is likely that these practices will continue to be improved due to increasing concerns regarding the presence of contaminants in estuarine and marine environments.

2.2.7.2.3 Technical Feasibility of Restoration Actions

Exhibit 2.15 presents an overview of the state of technical feasibility for restoration appropriate to subtidal cobble-gravel, sand, and silt-mud bottom habitats. A brief discussion of these restoration actions is presented below.

2.2.7.2.3.1 Natural Recovery

Monitoring of natural recovery is technically feasible. See Chapter 3 for a discussion of recovery.

2.2.7.2.3.2 Dredging/Material Removal

Direct restoration of contaminated subtidal benthic environments (e.g., cobble-gravel, sand, and silt-mud) prevents continued exposure of biota to contaminants in the sediments. The USACOE categorizes sediments according to material type that includes mud, peat and organic muck, clay, silt, sand, gravel and shell, and shale (rock). The largest volume of materials dredged in the United States are sand and silt sediments, with sand, gravel, and shell sediments second in magnitude (Pequegnat et al., 1978). Organic mucks and peat sediments, while only dredged in small volumes, are found in areas with potentially more severe contamination problems (e.g., harbors and estuaries).

As identified in section 2.2.6.6.2, there are several documented cases where restoration performed for contaminated subtidal habitats was direct material removal. This activity is typically performed using one or more types of dredging equipment to remove the contaminated sediment. Sediment dredging is a well-known practice and many millions of cubic yards of sediments are dredged each year using either mechanical or hydraulic dredge equipment to maintain navigable waterways. Where material removal is performed, corresponding disposal and/or treatment actions must also be conducted to ensure proper containment and/or remediation of sediment contaminants.

Exhibit 2.15 Overview of technical feasibility of subtidal estuarine and marine cobble-gravel, sand, and silt-mud bottom restoration.

	State of Feasibility	**Availability of Services and Materials**	**Key Constraints**	**Future Restoration Actions**	**Legal and Administrative Factors**
Natural Recovery	Generally feasible	Generally available	Little constraint	Unlikely that additional activity be required	Coordination of monitoring activities
Dredging/ Material Removal	Demonstrated technically feasible	Dredging operations conducted by either federal agencies or private contractors; equipment available in most geographic regions	Effectiveness depends on material characteristics and type of dredge equipment selected; appropriate treatment and/or disposal action as must be considered	Continued presence of contamination in sediments may require further dredging activity	Dredging activities require permit from authorized agency; depending on method of disposal selected, additional permits and administrative requirements may be applicable
Sediment Capping/Replace-ment	Demonstrated as technically feasible	Capping materials generally available in most regions; equipment and transport needs met by dredging contractors and/or USACE	Improper placement of cap hinders effectiveness; short-term effects on benthic biota; long-term monitoring required	Additional sediment placement if initial cap is eroded or displaced; long-term monitoring activities required to observe containment and associated effects	Permits may be required to perform in place containment activities; coordination with oversight agencies

Availability of Services, Equipment, and Materials

The majority of dredging operations conducted in U.S. waters are performed by the USACOE, the federal agency responsible for maintaining navigable waters. The USACOE is considered the expert agency on dredging activities and typically manages and conducts dredging projects in publicly-managed waters. The USACOE maintains its own dredging fleet, comprised of several types of equipment located in the geographic areas where the USACOE manages its activities (i.e., USACOE Districts). In addition, the availability of private contractors who provide dredging services to maintain privately operated ports and harbors is equally widespread throughout the U.S.

The following describes the types of dredging equipment available to conduct sediment removal activities and characteristics of their operation.

Mechanical dredge equipment. Mechanical dredges remove bottom sediments by directly applying mechanical force to dislodge and excavate the material. Types of mechanical dredges include the clamshell, dipper, dragline, and ladder dredges.

Clamshell dredges are often used for mechanically removing sediments. This type of dredge employs a crane mounted scoop, or shovel, that has two or three "jaws" that open as the clamshell is dropped to the bottom and close together as the device is lifted. The resuspension of sediments from clamshells is relatively low, especially with better designed models that are made to be relatively water-tight after closing. Clamshell dredges typically require a barge (unpowered) or scow (powered) for transport of dredged materials.

Dipper dredges are open top shovel dredges typically used to create new harbor or channel areas by removing rocky or heavily consolidated materials rather than dredging sediments. The heavy resuspension of sediments from this type of operation makes it unacceptable for dredging contaminated sediments unless effective resuspension controls (e.g., silt curtains) are in place.

Draglines and ladder dredges are often used for mining rather than for sediment removal. Both have high levels of sediment resuspension and are not as appropriate as other types of dredges for removal of contaminated sediments (Cullinane et al., 1990).

Hydraulic dredge equipment. Hydraulic dredges remove sediment in liquid slurry form using a vacuum pump and a dredge arm or pipe extended to the bottom to vacuum material. Hydraulic dredges that do not use any specialized attachments at the sediment end of the dredge arm are known, simply, as suction dredges. The dredge arm or pipe may use a mechanism on the bottom to dislodge materials that are then suctioned through a pipeline, cutterheads and dustpans are two such attachments. Dustpans, designed for the lower Mississippi to dredge large volumes in shallow water, have a high level of resuspension and are generally inappropriate for dredging contaminated sediments (Cullinane et al., 1990). Suction dredges, with or without the cutterhead attachment, are favored hydraulic dredges for removing contaminated sediments.

Hydraulic dredges also vary in their management of sediments. Most dredges remove the sediments and either use a pipeline to transport sediments or place the materials on a barge (i.e., unpowered) or scow (i.e., self-powered) moored alongside that transports the sediment to disposal or to a shoreside settlement pond. Hopper dredges, on the other hand, are hydraulic dredges equipped with settling bins on board to allow sediments to settle out of the slurry. These bins, or hoppers, are typically filled well past overflowing, allowing the waters from which most sediments have settled to run overboard. Assuming that these waters are contaminated by their contact with the sediments, this type of overflow operation is generally not appropriate for removal of contaminated sediments.

An advantage of hopper dredges, however, is that they can be used in specialized cases (e.g., in areas of strong surface currents) where the use of anchored suction/cutterhead dredges and/or barges or pipelines may be infeasible. In cases where open water disposal of dredged material is appropriate, the hopper dredge has an advantage in situations where a down pipe (e.g., the dredge arm modified) may be needed to properly place contaminated sediments on or near the bottom using the pipeline. The hopper dredge itself (i.e., via barge) transports sediment to the disposal site with its suction pipe on board.

Constraints

Many factors must be evaluated before dredging operations can be conducted. These factors include an evaluation of appropriate dredging equipment and the subsequent disposal and/or treatment alternatives for the contaminated dredged material. In addition, dredging activity may adversely affect the contaminated habitat by destroying biota in the sediments. Thus, the environmental effects of conducting sediment removal actions must also be taken into consideration. The following paragraphs discuss each of these factors and the constraints that may be incurred during application of sediment removal actions.

When selecting the appropriate dredge equipment used in specific subtidal habitats where bottom sediments may vary in their physical characteristics, each type of equipment should be considered with respect to the level of contamination present in the sediment. For example, the primary advantage of mechanical dredges is that little additional associated water is removed with the sediments. In contrast, the contact waters that are a by-product of hydraulic dredging may represent a major disadvantage when dredging hydraulically. One major advantage of hydraulic dredging is that the resuspension of contaminated materials can be kept to a minimum. The resuspension of contaminated sediments is a primary disadvantage of mechanical dredging.

Several other factors must be considered when selecting dredge types. These include:

- Physical characteristics of the material to be dredged. Materials with a large rock composition, such as cobble-gravel sediments, are most often dredged mechanically, while organic muck (e.g., in the form of silt-mud) may not be easily removed with a clamshell but require a suction dredge;

- Quantity of material dredged. For example, clamshell operations may be slower than pipeline dredging and inappropriate for very large jobs. Hopper dredges that self-contain the sediments may be more appropriate than constructing pipelines for a small operation;

- Dredging depth and surface water characteristics. Hydraulic dredging is typically limited to 50-60 feet deep waters, clamshells may be used to 150 feet or more; clamshells, cutterhead, and suction dredges typically need calm waters in which to be anchored to work; hopper dredges can run in rough water or high currents;

- Method of disposal. Pipeline dredges may be more appropriate near shore if upland or near-shore contained disposal facilities are to be used. Hopper dredges or hopper barges may be required for long distance transport to open water disposal sites, although floating pipelines have also been used when appropriate; and

- Type of dredges available. For example, some dredge types are more prevalent in the coastal areas where currents are more of a problem and distance to open water disposal sites is farther. In more remote areas where mobilization is more difficult, the dredge types available may not be appropriate for the site conditions, thus requiring additional effort to transport the appropriate equipment.

Once excavated, the dredged material must be disposed of or used. Due to the contamination, the sediments are assumed to be below quality for any useful application (e.g., beach nourishment, fill material, road construction). It is therefore necessary to consider disposal actions for the contaminated dredged material. Current disposal methods used for such applications include upland, near-shore, or open-water disposal areas designed to effectively manage the contaminants. These disposal actions are briefly described below:

Upland Disposal. Contaminated sediments may be disposed of on shore in a designated facility. Onshore facilities must, therefore, be concerned about the potential of leaching contaminants out of the disposed sediments and into the ground water. To avoid this result, specially lined and capped facilities may be required to contain contaminants. The sediments can be transported to the lined upland unit either via a pipeline if hydraulic dredging is used, or by truck where mechanical dredging is employed. Due to the concern with contamination by associated waters in an upland unit, slurries may not be acceptable or the contaminated waters may require some treatment before discharge. If associated slurry waters are of low enough concentration they may be overflowed back into waters surrounding a dredge (i.e., via a hopper dredge operating at overflow). The contaminated sediments could then be removed from the hopper and placed in trucks for transport to an upland unit.

Near-shore, Confined Disposal. A second disposal option often employed by the USACOE in maintenance dredging operations is to construct confined disposal areas near shore. Dredged materials are placed in these sites to allow settling of the sediments and return of the associated waters to open waters. The major advantage of this option is that the units can be placed close to near-shore dredging operations and hydraulically dredged materials can be piped directly to the units for settling. A major disadvantage is that control of the associated waters is difficult with these units. If associated waters are controlled or if discharge to local near-shore waters of this contaminated water is a concern, this option may not be available. A second disadvantage is that leachate cannot be easily controlled from these units. Because the units are built with dikes in open water, after filling with sediments the lower layers of the impounded sediments will remain saturated while the upper levels will remain unsaturated. The upper levels will require capping to control leaching from precipitation. The sediments in the intermediate levels, however, will be subject to saturation and draining as tides rise and fall, and leaching contaminants from these sediments cannot be controlled, presenting long-term concerns.

Open-water Disposal. A third disposal option employed by the USACOE in the disposal of dredged sediments from maintenance dredging is to transport the materials to off-shore open-water sites designated for ocean dumping. Sediments may be transported by pipeline under certain conditions (e.g., floating pipelines may be limited in navigation lanes or very rough waters) or by hopper dredge, barge, or scow. While a primary advantage of open-water disposal is cost, another advantage is the avoidance of leachate contamination of ground water from upland units or contamination of local near-shore waters from contained disposal facilities and the associated impacts on swimming, spawning, and fishing areas and near-shore wildlife.

Obviously, there is a concern with disposing contaminated sediments and associated waters in the open ocean. Controls are available for ensuring that impacts from deep sea disposal of contaminated sediments offshore are reduced. Control of the discharge plume may be achieved using the transport pipeline, the dredge suction arm on hopper dredges (which may require modification) or some other form of down pipe to allow the correct placement of sediments and associated waters on the bottom while isolating the material in the water column during descent. This reduces entrainment and negates the effects of currents and temperature stratifications. A diffuser may be attached to the discharge end of the down pipe system to slow the release velocity and redirect the plume to release the discharge parallel to the bottom. These activities reduce resuspension of the sediments and promote mounding.

Another control used to minimize impacts from deep-water disposal of sediments is capping the mound of contaminated sediments. There is considerable research on capping that is applicable to controls for contaminated sediments (e.g., Pequegnat et al., 1978; Cullinane et al., 1990). Capping materials may consist of inert materials, chemically active material, or sealing materials. Inert materials used to cover the contaminated sediments would include either clean dredged material (i.e., dredged for this purpose or taken from maintenance dredging operations) or excavated upland materials. Capping methods and sediment replacement activities are discussed in more detail under "Sediment Containment / Replacement" (see Section 2.2.6.6.3.3).

Depending on the type of disposal selected and the severity of the contamination in the sediments, treatment may or may not be required or desired prior to disposal. If contamination levels are assumed of low severity, disposal without treatment may be sufficient, especially if disposal controls (e.g., capping) are in place. Treatment of contaminated dredged material prior to disposal is not a widespread practice and there still exist some technical constraints with various treatment alternatives to preclude them from widespread application. The primary constraint is cost, due to the fact that many treatment methods being evaluated for contaminated sediment remain in the experimental stage. Some treatment methods available for consideration in the treatment of contaminated dredged material include the following:

- Physical separation. Physical separation of contaminants from the sediments presumes that most contaminants are bound to the finer materials found in sediments (e.g., sediments with silt-mud properties). Classification of the dredged materials into coarse and fine fractions should result in a relatively concentrated fine material fraction that could be managed while the remainder of the coarse fraction is released. The cost of such operations has not been evaluated at a field level, but is expected to be substantial. However, should upland or near-shore disposal be the preferred option, the high cost of physical separation may be cost-effective in that management cost would be lowered by handling less contaminated material (Cullinane et al., 1990); and

- Contaminant extraction. This process separates contaminants from the sediments using a solvent extraction operation. This treatment application to dredged material may have potential but the current level of knowledge remains limited (Cullinane et al., 1990).

The actions for treatment and/or disposal of contaminated dredged material must be thoroughly evaluated with respect to the level of contamination and the risk of further contaminant exposure as a result of actions taken. Major issues that may be considered in contaminated sediment restoration include the following, injury associated with environmental side effects from sediment removal or treatment, selection of appropriate restoration actions in the absence of clear criteria and experimental evidence, allocation of restoration costs, and attainment of restoration goals.

Future Restoration Actions

Additional restoration actions may be required if dredging activities do not remove the contaminated material adequately enough to foster concurrent natural recovery processes. If sediment removal causes additional injury to the benthic community, sediment replacement may be necessary. Additional dredging may be required if the contaminated sediment was not effectively removed during the initial dredging activities. Where natural processes do not effectively dilute or bury contaminated sediment, further sediment removal operations may be needed.

Replacing sediments in subtidal benthic habitats would require that clean fill be transported to the site and placed by pipeline or surface discharge to cover the excavated area to replace the amount of sediment removed. While technically feasible, this alternative is unlikely to be necessary except in shallow waters where the change in depth would be ecologically significant. Usually in deeper waters sufficient sediment exists beneath the removed sediments to allow the natural restoration of the ecosystem. In the rare cases where the removal of sediments would expose a substrate inadequate for recolonization, some backfilling activity may be required. Natural sedimentation by wave and current activity, however, will occur in most near-shore subtidal areas and circumvent the need for backfilling.

2.2.7.2.3.3 Sediment Capping/Replacement

An alternative action to sediment removal for the restoration of contaminated sediment involves the application of in place or *in situ* controls. Possible *in situ* controls consist of containment, treatment, or combinations of the two. In practice, however, *in situ* treatment of aquatic contaminated sediments is only in the experimental stage or performed on small scales. It is not considered a viable action by most management agencies (Marcus, 1991). Sediment containment or confinement therefore is the primary focus for application of *in situ* controls.

Contaminated sediment can be contained by placing a cap over the sediments or by combining capping with lateral confining structures, such as dikes (e.g., contained aquatic disposal sites). The material used for capping typically includes clean sands or silts, which are placed on top of the contaminated sediments. Confining structures are used in cases where cap materials may be displaced, such as on a sloping surface, or disturbed by natural or man-induced activity (e.g., wave action, navigational maintenance). Contained aquatic sites constructed to confine contaminated sediments also help ensure that capping materials are properly placed and they effectively cover the contaminated sediments.

Sediment confinement is only considered an appropriate restoration alternative under certain circumstances. These include:

- If natural recovery, or no-action, does not provide effective dispersement of contaminants;
- If the source of pollutant discharge is contained;
- If constraints of conducting sediment removal activities are too great (e.g., cost, environmental effects);
- If sufficient capping material is available; and
- If the site will not be unreasonably disturbed by natural or human intrusion (e.g., hydrological factors, dredging) (Marcus, 1991).

Availability of Services, Equipment, and Materials

Capping materials may include clean dredged sediments from a maintenance dredging operation or material that is excavated from an upland site. Typical capping operations include the placement of suitable materials over the sediments using a ratio of clean material to contaminated sediment. Based on communication with and published sources from the USACOE, a generally accepted ratio of capping material to contaminated sediment for an adequate cap on contaminated sediment ranges from three to five parts clean material to one part contaminated (USACOE, 1989; Averett and Palermo, 1989; Holliday, 1992). Clean dredged material is a preferred capping material due to its similar composition to contaminated bottom sediment (in any given area), as well as the ease of acquisition, transport, and placement of such materials. Capping operations may be planned to coordinate with maintenance dredging operations so that clean dredged material may be used in the cap.

The availability of clean dredged material and other sources of suitable fill material will vary by geographic location. The availability of clean material for use in capping operations often depends upon the schedule for maintenance dredging whereby fill material is produced or may rely on access to upland sites for material. Also, clean dredged material is often used in beneficial use applications (e.g., beach nourishment) and, therefore, significant quantities of available material may be earmarked for this type of operation. In this case, additional costs may be incurred to obtain material from sources other than maintenance dredging operations. It is common practice for capping operations to use clean material which is located nearby the contaminated site in order to defray costs of transport.

If clean material is obtained from maintenance dredging operations, capping activities may be scheduled to coordinate with the maintenance dredging operations so that additional equipment requirements are not needed to move and place the capping material. If suitable capping material is provided from upland sources, equipment requirements needed to perform site containment include material transport from source to the contaminated aquatic site. These activities would typically involve mobile transport of the material to a barge equipped with necessary controls for placement of material onto the contaminated bottom sediment. The availability of such equipment is widespread in most regions with marine and estuarine resources and may be contracted either from federal agencies such as the USACOE or from private contractors who specialize in dredging operations.

Constraints

One advantage of capping contaminated sediments as a restoration action is that materials are not resuspended into the aquatic environment as they can be when sediments are removed. Also, surrounding benthic organisms are prevented or restricted from contact with the contaminated sediments after placement of the capping material. A disadvantage of *in situ* capping, however, is that a large surface area of bottom sediments may require capping, thereby requiring the placement of large quantities of clean material. The placement of such large quantities of material on the local benthic environment may cause some environmental detriment in the short-term. Another logistical disadvantage, and one very important to the selection of the preferred restoration alternative, is that *in situ* capping cannot be used in an area where the cap may be disturbed either by natural forces (e.g., major storms or earthquakes and slides) or anthropomorphic activities (e.g., shipping, maintenance dredging, mining) (Averett and Palermo, 1989; Averett et al., 1990).

Additional constraints related to capping operations include problems associated with the inaccurate emplacement of materials on the habitat bottom and the potential for erosion processes to alter the effectiveness of the cap. Specialized equipment is available to minimize problems associated with misdirected capping material so that the initial cap is effectively placed. Also, it is essential to develop long-term monitoring procedures to detect erosion and ensure that the contaminants do not bioaccumulate in the biota (Averett and Palermo, 1989; Marcus, 1991).

Future Restoration Actions

As identified above, long-term monitoring should be conducted to observe the effectiveness of the cap and determine additional management procedures based on results of initial site containment.

2.2.8 Riverine and Lacustrine Shorelines

The following discusses restoration actions and the related technical feasibility of restoration for riverine and lacustrine (lake) freshwater habitats.

2.2.8.1 Rocky Shores

- Natural Recovery;
- Sandblasting;
- Steam Cleaning;
- Flushing; and
- Bioremediation.

2.2.8.1.1 Oil Related Literature

The same literature sources used in the evaluation of the technical feasibility of restoration actions in intertidal rocky shore habitats (Section 2.2.6.1) are applicable to riverine and lacustrine rocky shore habitats. In addition to the sources detailed in the intertidal section, Foley and Tresidder (1977) evaluated pressure washing and steam cleaning in freshwater rock shore environments. Fremling (1981) also evaluated pressure washing of rip rap shorelines in a lacustrine environment.

2.2.8.1.2 Non-oil Related Literature

The literature that discusses restoration in rocky shore intertidal habitats (see Section 2.2.6.1) was also used to evaluate technical feasibility in riverine and lacustrine rock shorelines. This literature deals primarily with oil contamination.

2.2.8.1.3 Technical Feasibility of Restoration Actions

The feasibility of each action is summarized in the previously-presented Exhibit 2.10 and is discussed below. In general, restoration of riverine and lacustrine shorelines is subject to the same feasibility issues as similar estuarine and marine intertidal habitats.

2.2.8.1.3.1 Natural Recovery

Monitoring of natural recovery is always technically feasible. See Chapter 3 for discussion of recovery.

2.2.8.1.3.2 Sandblasting

The technical feasibility of sandblasting in riverine and lacustrine rocky shore habitats is similar to that in rocky intertidal habitats. See Section 2.2.6.1.3.2. for a detailed discussion.

2.2.8.1.3.3 Steam Cleaning

In addition to the discussion provided in Section 2.2.6.1.3.2. regarding the literature concerning steam cleaning in rocky marine intertidal habitats, Foley and Tresidder (1977) report the use of steam cleaning of rock, steel, and wood surfaces following the *Nepco 140* barge oil discharge in the St. Lawrence river in 1976. Steam cleaning was used to remove residual oil stains on rock shores and manmade structures after initial cleaning was conducted. While this activity was used as a restoration action, it was used in conjunction with open water and shoreline cleanup recovery efforts.

The technical feasibility of steam cleaning in riverine and lacustrine rocky shore habitats is similar to that rocky intertidal habitats. See Section 2.2.6.1.3.3. for a detailed discussion.

2.2.8.1.3.4 Flushing

In addition to the literature discussed previously for flushing in estuarine and marine intertidal habitats, Foley and Tresidder (1977) and Fremling (1981) discuss the use of pressure washing in riverine and lacustrine environments. The activities described in both these sources are high pressure spraying. Foley and Tresidder describe the use of "water blasting" on rock, steel, and wood surfaces following cleanup activities subsequent to the *Nepco 140* barge discharge in the St. Lawrence River. Fremling notes that high pressure sprays were used in an attempt to remove the 18-inch-wide "tar-like fraction" from rip rap sections along the 3.6-mile perimeter of Lake Winona following the long-term release of heating oil.

The technical feasibility of flushing in riverine and lacustrine rocky shore habitats is similar to that in rocky intertidal habitats. See Section 2.2.6.1.3.3. for a detailed discussion.

2.2.8.1.3.5 Bioremediation

The technical feasibility of bioremediation in riverine and lacustrine rocky shore habitats is similar to that in rocky intertidal habitats. See Section 2.2.6.1.3.3. for a detailed discussion.

2.2.8.2 Cobble-Gravel Shores

- Natural Recovery;
- Flushing;
- Sediment Washing;
- Sediment Agitation; and
- Bioremediation.

2.2.8.2.1 Oil Related Literature

The same literature sources used in the evaluation of the technical feasibility of restoration actions in intertidal cobble-gravel shore habitats (Section 2.2.6.1) are used for similar riverine and lacustrine habitats. In addition, the observations of Little and Little (1991) regarding the restoration efforts of rock and cobble shores were evaluated.

2.2.8.2.2 Non-oil Related Literature

The literature related to the restoration of cobble and gravel shorelines is primarily oil discharge related.

2.2.8.2.3 Technical Feasibility of Restoration Actions

The feasibility of each restoration action is similar to that for estuarine and marine cobble-gravel shores. Technical feasibility of actions were previously summaried in Exhibit 2.11 and Section 2.2.6.2.3.

2.2.8.3 Sand Shores

- Natural Recovery;
- Flushing;
- Sediment Washing;
- Sediment Agitation;
- Bioremediation; and
- Incineration.

2.2.8.3.1 Oil Related Literature

The oil discharge related literature used to examine technical feasibility of restoration actions in freshwater sand shoreline environments is the same as that used to evaluate feasibility in intertidal sand shore habitats (see Section 2.2.6.). In addition to the sources detailed in that section, Fremling (1983) provided details on pressure washing of oil stains in a lacustrine environment.

2.2.8.3.2 Non-oil Related Literature

The literature that deals with restoration of sand shore habitats is primarily oil discharge related.

2.2.8.3.3 Technical Feasibility of Restoration Actions

The technical feasibility of each action is similar to that for estuarine and marine sand shores, as summarized in Exhibit 2.12. See Section 2.2.6.3.3 for discussion.

2.2.8.4 Silt-Mud Shore

- Natural Recovery;
- Sediment Removal/Replacement; and
- Bioremediation.

2.2.8.4.1 Oil Related Literature

The oil discharge related literature used to evaluate the technical feasibility of silt-mud shoreline restoration in riverine and lacustrine environments is the same as that used for mud flat intertidal environments (see Section 2.2.6.4.1.). In addition to these sources, Smith (1987) and the American Petroleum Institute (1991) were used as references for sediment removal and replacement operations.

2.2.8.4.2 Non-oil Related Literature

The literature dealing with the restoration of silt-mud shorelines is primarily oil discharge related.

2.2.8.4.3 Technical Feasibility of Restoration Actions

The technical feasibility of restoration actions is similar to that for estuarine and marine mud flats, as summarized in Exhibit 2.13. See Section 2.2.6.4.3 for discussion in addition to that below.

2.2.8.4.3.1 Natural Recovery

Monitoring of natural recovery is always technically feasible. See Chapter 3 for a discussion of recovery.

2.2.8.4.3.2 Sediment Removal/Replacement

Smith (1987) documents the use of sediment removal and replacement as a restoration action for a silt-mud shoreline of a lake in Portland, Oregon. An oil discharge occurred in 1985, which was caused by a separator pond malfunction at a waste oil treatment and recycling facility. In the course of the cleanup, the water level dropped one foot, leaving stranded oil in a band on the shoreline approximately 10 feet wide.

The restoration effort consisted of topsoil removal and replacement on the shoreline, along with planting of grass. Topsoil had been removed to a depth of 2 inches over an area from the shoreline to a point where no further oil was discernible. Topsoil was replaced using material from a local supplier. After the topsoil was spread, it was seeded with fescue grass. Sludge from a paper mill was suggested as a soil amendment to replace lost humus-rich soil. However, concern was raised about the use of the sludge and, at it was decided to replace the oil-contaminated soil with common topsoil.

The American Petroleum Institute (1991) developed a restoration scenario for conditions following a discharge of gasoline into the high energy Wolf Lodge Creek. Restoration conducted following the discharge consisted of streambed agitation and is discussed in Section 2.2.9.2.3.3. API suggests a restoration scenario that includes the manual and mechanical removal and replacement of streambank soils in addition to streambed agitation.

The technical feasibility for the removal and replacement of contaminated silt-mud shores is the same as for intertidal mud flat habitats. Refer to Section 2.2.6.4.3.3. for a further explanation of the factors affecting removal and replacement.

2.2.8.4.3.3 Bioremediation

Bioremediation of freshwater silt-mud shorelines is similar to that in intertidal mud flat habitats. The discussion of technical feasibility found in Section 2.2.6.4.3.3 applies to riverine and lacustrine environments as well.

2.2.9 Riverine Bottom

The following section summarizes restoration actions for riverine bottom environments.

2.2.9.1 Rock Bottoms

As identified in Section 2.2.7.1. for estuarine and marine subtidal rock bottom habitats, the restoration action applicable to these habitats is natural recovery. Due to limited available literature on the restoration of rock bottom river and stream habitats injured by pollutants and the similarity of this habitat to estuarine and marine rock bottom habitats, monitoring of natural recovery is the only feasible action for river and stream rock bottom habitats. Refer to Section 2.2.7.1. for a discussion of the technical feasibility of this restoration action.

2.2.9.2 Cobble-Gravel, Sand, and Silt-Mud Bottoms

Restoration actions for riverine cobble-gravel, sand, and silt-mud bottom habitats injured by contaminants are similar to two actions described above for subtidal estuarine and marine habitats (see Section 2.2.7.2.). One additional action, sediment agitation, is also considered for riverine habitats. For these habitats, restoration actions include the following:

- Natural Recovery;
- Dredging/Sediment Removal; and
- Sediment Agitation.

The following sections summarize available literature related to river and stream restoration and discuss the technical feasibility of each restoration action.

2.2.9.2.1 Oil Related Literature

Cases of oil discharge related restoration of river and stream bed habitats are not as well documented in the literature as those involving sediment contamination in estuaries or marine habitats. One case involving a fuel discharge in the Savannah River (Brown, 1989) identified the effects of oiling to be minimal in bottom sediments since the remaining surface oil after cleanup was left to natural dispersion. Adverse impacts from this discharge focused primarily on injuries to wetlands, waterfowl, shellfish, and other vegetation. Two other restoration cases studies identified in the literature refer to a gasoline discharge located in a Northern Idaho creek (Graves, 1985; API, 1991). Creek restoration was performed using a stream agitation action, a method that is technically feasible in shallow water habitats.

2.2.9.2.2 Non-oil Related Literature

Non-oil related impacts can include stresses on the habitat due to the deterioration of water quality (i.e., from temperature changes, excessive turbidity), substrate modification, flow fluctuations, and biotic interactions. The restoration of rivers and streams affected by non-oil related impacts is documented in the following literature sources:

- Bechly (1981) describes a case study of the restoration efforts performed in the Cowlitz and Columbia Rivers after the Mount St. Helens volcanic eruption. Excavation of large amounts of sediment was performed in both rivers;

- Institute of Environmental Sciences (1982) evaluates the George Palmiter method of river restoration. This method was designed as a labor intensive method of preventing erosion and flooding;

- Herricks and Osborne (1985) discuss the restoration and protection of water quality in streams and rivers. This chapter identifies the uses and impacts of restoration and discusses general approaches to restoration and protection;

- Starnes (1985) presents an overview of stream reclamation approaches and case studies where coal mining related impacts were restored. These approaches include methods of instream habitat restoration;

- Gore et al. (1988) summarize methods of river and stream restoration and identify the need to eliminate pollutant load in surface runoff, control erosion, and sustain faunal habitats;

- National Research Council (NRC, 1992) presents a thorough assessment of river and stream restoration, identifies case studies of historical restoration projects, and evaluates habitat functions, stresses, and effective management actions.

Restoration actions identified for non-oil related impact to river and stream habitats emphasize actions for the rehabilitation of ecosystem impacts related to increased sediment loads, poor water quality, and declines of habitat species. These injuries can be restored through actions which allow dilution or transfer, removal, or isolation of the pollutants.

2.2.9.2.3 Technical Feasibility of Restoration Actions

Exhibit 2.16 presents an overview of the technical feasibility of the restoration actions appropriate to riverine cobble-gravel, sand, and silt-mud bottom habitats. A brief discussion of these restoration actions are presented below.

2.2.9.2.3.1 Natural Recovery

Monitoring of natural recovery is technically feasible. See Chapter 3 for a discussion of recovery.

2.2.9.2.3.2 Dredging/Sediment Removal

Sediment removal using dredging actions to eliminate contaminated bottom sediment is a technically feasible approach for subtidal river and stream habitats (Herricks and Osborne, 1985; NRC, 1992). River dredging is a common method used to maintain navigational waterways. However, this practice is not as common for use in smaller streams. The technical feasibility of dredging and replacement of bottom sediments as a restoration action was discussed above for estuarine and marine subtidal habitats (see Section 2.2.7.2.3.2). These factors are also applicable to riverine bottoms.

2.2.9.2.3.3 Sediment Agitation

A restoration action applicable to shallow river and stream habitats is stream bed agitation. Graves (1985) describes the application of stream bed agitation after a gasoline discharge in Wolf Lodge Creek, Idaho. This restoration action is also identified in API (1991). In this application, officials concluded that after the initial cleanup, additional restoration was necessary because some of the dischargeed gasoline had been trapped in the stream bed underneath gravel and debris. Gasoline continued to leach from these areas contaminating the creek waters.

Exhibit 2.16 Overview of technical feasibility of riverine cobble-gravel, sand, and silt-mud bottom restoration.

	State of Feasibility	**Availability of Services and Materials**	**Key Constraints**	**Future Restoration Actions**	**Legal and Administrative Factors**
Natural Recovery	Generally feasible	Generally available	Little constraint	Unlikely that additional activity be required	Coordination of monitoring activities
Dredging/Sediment Removal	Demonstrated technically feasible	Dredging operations conducted by either federal agencies or private contractors; equipment available in most geographic regions	Effectiveness depends on material characteristics and type of dredge equipment selected; appropriate treatment and/or disposal action as must be considered	Continued presence of contamination in sediments may require further dredging activity	Dredging activities require permit from authorized agency; depending on method of disposal selected, additional permits and administrative requirements may be applicable
Sediment Agitation	Demonstrated as technically feasible	Heavy equipment, labor, and materials generally available	Feasible only in shallow water areas	Potential need for vegetation and additional soil removal if contamination poses long-term threat	Little constraint; coordination of activities with appropriate authorities

Stream bed agitation was applied in an attempt to release gasoline trapped in the stream bed. A bulldozer was used to agitate the gravel creek bed by dragging the blade backward throughout the entire stream bed. A tightly wound chain link fence was attached to the bottom of the bulldozer blade to smooth the stirred stream bed and to facilitate agitation of small gravel and debris. Three inches of stream bed were turned over by dragging the bulldozer blade. Sorbent blankets were deployed at about one-quarter mile intervals in slow-moving areas of the stream to capture released gasoline. Sorbent and contaminant boom were placed downstream from the agitation area to capture any gasoline that was not removed by the sorbent blankets.

Availability of Services, Equipment, and Materials

Equipment requirements for the streambed agitation action include the use of a bulldozer with rake attachments and sorbent materials to contain remaining pollutants once agitation is implemented. Heavy machinery and trained operators are typically available through local private contractors. Materials used to absorb excess pollutants can generally be obtained through local discharge response agencies or contractors.

Constraints

The case study identified above concluded that stream bed agitation appears to be a technically feasible method of removing gasoline trapped in shallow stream bed sediments (Graves, 1985). The action, however, is only applicable to shallow streams with low to moderate current that allow the bulldozer to operate. The stream bed in which it was applied consisted of gravel. It was not attempted in an area of the stream where the bottom was silt because there was concern that stirring up too much sediment would have an adverse effect on the stream.

Future Restoration Actions

Additional restoration actions following the streambed agitation action that may be feasible and warranted include removal of injured riparian vegetation and contaminated streambank soils. These activities would be necessary in cases where there is potential for significant long-term impacts from the pollutant.

2.2.10 Lacustrine Bottom

The following summarizes restoration actions for lacustrine bottom environments.

2.2.10.1 Rock Bottom

As identified in Section 2.2.7.1. for estuarine and marine subtidal, and Section 2.2.9.1 for riverine, rock bottom habitats, the only restoration action applicable to these habitats is monitoring of natural recovery. Lacustrine rock bottoms are assumed to be similar.

2.2.10.2 Cobble-Gravel, Sand, and Silt-Mud Bottom

Restoration actions for lacustrine cobble-gravel, sand, and silt-mud bottom habitats injured by contaminants are similar to those actions described above for subtidal estuarine and marine habitats (see Section 2.2.7.2.). For these habitats, restoration actions include:

- Natural Recovery;
- Dredging/Sediment Removal; and
- Sediment Capping.

The following sections summarize available literature related to lake restoration and discuss the technical feasibility of each restoration action.

2.2.10.2.1 Oil Related Literature

Oil related lake restoration is not extensively documented in the literature. One case study identified oil discharge cleanup actions performed in Lake Winona, Minnesota, due to a fuel discharge (Fremling, 1981). Post-cleanup actions involved artificial circulation of the lake to purge the lake of residual oil. Contacts with scientific experts regarding ongoing lake restoration actions also confirmed that the science of oil-related restoration is not widely developed or documented (Peterson, 1993; Lazorchak, 1993).

2.2.10.2.2 Non-oil Related Literature

Restoration actions for lakes degraded by non-oil related factors are typically employed to modify lake water quality and shift the lake system closer to its original state. Non-oil related impacts to lacustrine systems that may warrant restoration actions include the presence of high levels of nutrients in the sediment, excessive sedimentation, the presence of toxic materials other than oil in the sediment, and increased aquatic macrophyte growth.

The most common restoration actions include sediment removal using dredging equipment and sediment covering (i.e., capping) to contain or control the source of degradation (e.g., presence of toxic sediment, excess nutrient releases). The following literature sources identify case studies where these actions were employed in lacustrine habitats and evaluate management strategies associated with each.

- Peterson (1979) addresses the positive and negative aspects of dredging freshwater lakes and evaluates the types of effective dredge equipment for sediment removal. Examples of successful dredging projects performed in lake systems are also presented;

- Cooke (1980) evaluates the process of covering bottom sediments as a restoration action to control macrophytes and sediment nutrient release;

- Welch (1981) describes the dilution/flushing action used in eutrophic lacustrine systems to alter the high nutrient content. Case studies of this action are presented;

- Peterson (1982) presents information of the effectiveness of sediment removal as a lake restoration action. This includes an evaluation of the action, considerations for sediment removal, and case histories where this action has been employed;

- Cooke (1983) reviews several lake restoration actions for use in lake systems. These include sediment removal, nutrient/silt diversion, dilution/flushing, phosphorus inactivation, and sediment covers;

- Welch and Cooke (1987) evaluate lake management actions which address the restoration of lakes with poor water quality;

- Bjork (1988) presents a summary of several lake restoration case studies which employed actions such as sediment removal and *in situ* sediment capping to control and immobilize problem elements in the system;

- Environmental Protection Agency (1988b) presents a review of effective in-lake restoration actions which have been found to be effective, long-lasting, and generally without significant negative impact when used properly. Sediment removal is evaluated in this review; and

- National Research Council (NRC, 1992) presents a chapter on lake restoration which evaluates the range of stresses imposed on lacustrine systems, and the various actions used to restore lake quality to its natural state. This review identifies sediment removal as the available method to restore lakes degraded by toxic sediments.

2.2.10.2.3 Technical Feasibility of Restoration Actions

Exhibit 2.17 presents an overview of the state of technical feasibility for the restoration actions appropriate to lacustrine cobble-gravel, sand, and silt-mud bottom habitats. A brief discussion of these actions are presented below.

2.2.10.2.3.1 Natural Recovery

Monitoring of natural recovery is technically feasible. See Chapter 3 for a discussion of recovery.

2.2.10.2.3.2 Dredging/Sediment Removal

Sediment removal using dredging actions to eliminate contaminated bottom sediment is a technically feasible approach for lacustrine habitats (Peterson, 1978; Cooke, 1983; Peterson, 1982; Bjork, 1988; EPA, 1988b; NRC, 1992). Sediment removal is one of the most commonly prescribed actions for long-term lake improvement. Its main purposes are to remove toxic materials, macrophytes, and nutrient-rich sediments as well as to deepen lakes. The technical feasibility of dredging and replacement of bottom sediments as a restoration action was discussed above for estuarine and marine subtidal habitats. These factors are also applicable to lacustrine habitats (see Section 2.2.7.2.3.2).

2.2.10.2.3.3 Sediment Capping/Replacement

As discussed for subtidal estuarine and marine bottom habitats, sediment capping is a technically feasible action for the containment of contaminated sediment. This method of restoration, as a contaminant control measure, is widely practiced and evaluated and provides an effective and economical action for managing contaminated bottom sediments and for the prevention of macrophyte growth in lakes (Cooke, 1980, 1983; Bjork, 1988; Averett et al., 1990). The technical feasibility of a sediment cap is dependant upon specific-site conditions. Refer to Section 2.2.7.2.3.3 for further discussion of these factors.

Exhibit 2.17 Overview of technical feasibility of lacustrine cobble-gravel, sand, and silt-mud bottom restoration.

	State of Feasibility	**Availability of Services and Materials**	**Key Constraints**	**Future Restoration Actions**	**Legal and Administrative Factors**
Natural Recovery	Generally feasible; favorable environmental conditions improve effectiveness	Generally available	Little constraint	Unlikely that additional activity be required	Coordination of monitoring activities
Dredging/Sediment Removal	Demonstrated technically feasible; effectiveness varies based on site conditions and type of equipment used	Dredging operations conducted by either federal agencies or private contractors; equipment available in most geographic regions	Effectiveness depends on material characteristics and type of dredge equipment selected; appropriate treatment and/or disposal action a must be considered	Continued presence of contamination in sediments may require further dredging activity	Dredging activities require permit from authorized agency; depending on method of disposal selected, additional permits and administrative requirements may be applicable
Sediment Capping/ Replacement	Demonstrated as technically feasible; selection of this alternative depends on site conditions and related factors	Capping materials generally available in most regions; equipment and transport needs met by dredging contractors and/or USACE	Improper placement of cap hinders effectiveness; short-term effects on benthic biota; long-term monitoring required	Additional sediment placement if initial cap is eroded or displaced; long-term monitoring activities required to observe containment and associated effects	Permits may be required to perform in place containment activities; coordination with oversight agencies

2.3 Biological Natural Resource Restoration

In addition to habitat restoration, fish and wildlife populations that live in these habitats may also require restoration. Several technically feasible restoration alternatives exist. Restoration actions typically include natural recovery monitoring, restocking, and various types of habitat enhancement, protection, and management practices.

Natural recovery, or no action (except monitoring), is typically used when no other restoration actions exist or would cause more injury if implemented. All actions require periodic monitoring of the area to ensure that recovery is occurring as expected.

The objective of restocking is to facilitate the recovery process by introducing or stocking species the same as or comparable to those injured. Although restocking is beneficial in many situations, there are potential problems and disadvantages resulting from the process and it may not be successful. These issues are discussed in Section 3.3.

Each of the following subsections: summarizes the oil discharge and non-oil discharge related literature, briefly describes each restoration action and discusses the technical feasibility of each action for shellfish (Section 2.3.1), fish (Section 2.3.2), reptiles (Section 2.3.3), birds (Section 2.3.4), and mammals (Section 2.3.5).

2.3.1 Shellfish

The restoration actions for restoring shellfish populations include:

- Natural Recovery;
- Reef Reconstruction;
- Hatchery and Seeding of Beds (restocking);
- Habitat Restoration and Enhancement;
- Modification of Fishery Management Practices; and
- Habitat Protection and Acquisition.

Monitoring is always feasible. A complete discussion of the technical feasibility of mollusc reef reconstruction is provided in Section 2.2.4 (Mollusc Reefs).

Hatchery and seeding programs exist for other types of shellfish and invertebrates. A number of states have seeding programs for clams and other molluscs. For example, Washington state plants hatchery-raised juvenile geoduck clams throughout Puget Sound. As the actions are generally technically feasible, the choice of the seeding alternative is dependent on effectiveness and success, as well as cost, discussed in detail in Sections 3.3 and 4.3, respectively.

The other restorations for shellfish are analogous to those for fish. See below for discussion of these actions.

2.3.2 Fish

Five general approaches have been used and documented as technically feasible for restoring injured fish populations. These actions include:

- Natural Recovery;
- Restocking/Replacement;
- Habitat Restoration and Enhancement;
- Modification of Fishery Management Practices; and
- Habitat Protection and Acquisition.

Habitat restoration and enhancement consists of improving the infrastructure of the habitat used by the fish surviving contamination. There are many forms of habitat enhancement, including construction of artificial reefs, development of spawning channels, construction of stream channel modifications, initiation of liming programs for acidic river environments, and improvement of fish passageways. These actions may be mitigating measures for the injury caused by oil discharges.

Modification of fishery management practices includes the initiation of policies that temporarily reduce or eliminate recreational and commercial harvesting of specific fisheries injured by contamination. The object is to allow the fishery population to recover from the effects of contamination without negative interference from harvesting.

Habitat protection and acquisition consists of designating areas as off-limits for human uses that would otherwise be open. The objective is to facilitate recovery of injured populations.

It is important to recognize that the selection of actions may differ depending upon whether the emphasis is on restoring the fish populations or the services provided by the fishery. The focus in this document is on the former, with the assumption that services will follow. However, services might be restored by replacement alternatives, such as providing additional fisheries or fishing areas.

The technical feasibility of each restoration action is described in greater detail below. Refer to Chapter 3 for discussions of effectiveness and success.

2.3.2.1 Oil Related Literature

Following the *Exxon Valdez* oil discharge, several reports were developed that describe restoration actions proposed for natural resources injured by the discharge. One such document by the Exxon Valdez Oil Spill Trustees (1992b) provides a summary of the habitats and species injured and gives brief descriptions of several potential restoration actions for these resources. Also included in the report is the rationale behind rejecting certain restoration actions previously considered. This report does not represent the final and complete restoration plan for the *Exxon Valdez* discharge, but it does represent the most recent and comprehensive oil discharge restoration plan available. This plan provides several restoration actions for injured fisheries, including intensifying or implementing recreational and commercial fishery management practices, enhancing fishery habitats (e.g., improvement of spawning substrates and establishment of alternative salmon runs), and eliminating sources of persistent contamination of spawning substrates.

Cairns and Buikema (1984) discuss the importance, vulnerability, and recovery potential of various natural resources susceptible to adverse impacts from oil discharges. They provide insight on some issues related to the restoration of fisheries injured by an oil discharge. In addition to suggested methods of assessing the impact of a discharge on fisheries, several fishery restoration actions are recommended including natural recovery monitoring, hydroelectric dam fish ladders, removal of massive pollutant sources, and the control of habitat invaders (e.g., sea lampreys).

2.3.2.2 Non-oil Related Literature

Section 3.3.2 contains a detailed discussion of restoration actions for fish populations. It focuses on effectiveness and success of technically feasible actions. The following is an overview of feasible actions.

Most fishery restoration actions relate to general restocking and hatchery research. Since this science is relatively well developed and documented, more discussion of the findings is provided here than for other resources.

Smith et al. (1990) describe the hatchery production process of advanced juveniles (phase II) and subadults/adults (phase III) striped bass and striped bass hybrids in earthen ponds. They provide information on pond design, pre-stocking pond preparation, acclimation and estimation of mortalities, stocking densities, feeding, monitoring, growth and survival, water quality sampling management, predators and competitors, diseases, vegetation, and harvesting.

The "Lake Superior Annual Report" for 1987, compiled by the state of Minnesota, discusses changes in the fish populations of Lake Superior and provides information on the monitoring, restocking, and other control methods of these fish populations. The changes in the fisheries of Lake Superior are in part caused by excessive harvesting and the introduction of several new species, including the sea lamprey, rainbow trout, and Pacific salmon. The report focuses on the impact of the sea lamprey on lake trout and the subsequent attempts to restore the lake trout population. Methods of reestablishing the lake trout fishery through controlling the sea lamprey, limiting commercial harvest, and stocking the lake with juvenile lake trout are described in this report.

In 1978, Nelson et al., of Enviro Control, Inc., prepared a handbook sponsored by the U.S. Department of the Interior which summarizes almost 300 fish and wildlife habitat and population improvement actions. The alternatives discussed include enhancement actions proven effective during previous dam and reservoir projects or determined to be potentially effective by experts in the field. A brief summary of each action provides engineering features, hydrological effects, biological effects, relative costs, and references. The fish and wildlife habitat improvement actions are reservoir flood basins, reservoir conservation pools, dam discharge systems, streamflows, riffles, and pools, streamside protection, and general practices. The fish and wildlife population improvement actions are fish propagation, fish passage, fish stocking and control, wildlife propagation and control, and wildlife protection at canals.

Bell et al. (1989) evaluate the biological, physical, and economic effectiveness of eight manufactured artificial reef structures. These structures were tested at sites off the coast of South Carolina as part of the state's Marine Artificial Reef Program. Although the evaluation is on-going to assess long-term effects, observation within the first three years of the study led to several preliminary conclusions and recommendations. Bell et al. describe the background of South Carolina's Marine Artificial Reef Program, methodology used for this study, specifications of the eight manufactured reef structures tested, economic cost of each reef structure type, and preliminary results and conclusions of the study.

Prince and Maughan (1978) present and discuss several biological and cost issues relevant to the development of freshwater artificial reefs. The biological issues addressed include fish abundance, fish colonization, fish harvest rates, and fish production in freshwater environments in relation to the existence of artificial reefs. The discussion on cost issues emphasized the possibility of using donated equipment, supplies, and labor to construct artificial reefs. This discussion was based on an actual artificial reef development program for Smith Mountain Lake in Virginia.

Feigenbaum et al. (1989) present methodologies, results, and conclusions from a three-year artificial reef study program in the Chesapeake Bay supported by a mitigation fund. The study experimented with various reef structures and sites. The stress levels and stability of the structures were tested by placing them in both the bay and nearby coastal waters. Feigenbaum et al. (1989) also present success rates of the various reef structures and sites for attracting fish populations and increasing catch rates. Recommendations of the best structural types and reef locations were derived based on the results of the study.

Duedall and Champ (1991) provide an international viewpoint of artificial reef design and construction. They discuss the various groups currently involved in the design and construction of artificial reefs, common materials used in reef construction worldwide, various functions of artificial reefs, biological benefits derived from reefs, factors involved in selecting an appropriate artificial reef site, and new developments of artificial reefs in Japan.

Hueckel et al. (1989) describe a mitigation project in Washington that involved the construction of an artificial reef. The reef was developed in a nearby sand bottom area to mitigate the loss of an area of rocky subtidal habitat destroyed from a shoreline fill project. One-half of the sand bottom area (2.83 ha) was covered with 181,400 metric tons of quarry rock ranging in size from 0.3 meters to 1.2 meters in diameter. The reef structures were placed approximately 15 meters apart.

Knatz (1987) describes three projects under consideration as mitigation for port landfill development in Southern California. One project consists of constructing an artificial reef near the Port of Long Beach under the guidelines of state and federal wildlife agencies. The other projects under consideration are two wetland habitat enhancement projects near the port. The determination of adequate mitigation of a development project and the concept of mitigation banking are discussed. The relative technical concerns and cost estimates are provided for each project.

McGurrin and Fedler (1989) evaluate the planning, siting, and socio-economic impacts associated with the rigs-to-reefs development program, specifically the Tenneco II artificial reef project. This project consisted of transporting three obsolete petroleum platforms from Louisiana to south Florida. The platforms now serve as a large artificial reef site for recreational fishermen.

Frissell and Nawa (1992) present the results from a study conducted on fishery habitat enhancement with artificial stream structures in Oregon and Washington. Various stream structure types were placed at several project sites and evaluated to determine the rates and possible causes of deterioration of each structure. The results revealed no direct correlation between the rate of failure and structural design. However, the characteristics of the stream in which the artificial structure was located had some relationship with the rate of structural failure. Frissell and Nawa provide conclusions and recommendations about the success and effectiveness of artificial stream structures developed from results of their study.

Smallowitz (1989) discusses the effects that the increasing number of hydroelectric dams in the Northwest have had on the annual runs of salmon and trout. The program to alleviate the injury inflicted on these migrating fish populations was initiated by the Northwest Power Act. The program includes both the enforcement of management practice policies and the installation of mechanical fish passageways around or through the dams. Several demonstrated fish passageway improvement actions are described.

Gore et al. (1988) summarize the issues and alternatives associated with the restoration of rivers and streams. Some of the considerations include proper hydrology, improved water quality, adequate riparian vegetation, appropriate distribution of macroinvertebrates, and adequate planning and monitoring of the restoration effort. After most of the river or stream infrastructure is established, efforts can be concentrated on the enhancement of fish habitats. Gore, et al. (1988) suggest the use of artificial stream structures based on a literature review. These structures include various current deflectors, dams, boulder placements, trash catchers, and bank covers.

Wesche (1985) discusses many aspects of river and stream restoration often required following channel modification, including a description of the impacts on the habitat, and guidelines for the planning, application, construction, and installation of various reclamation structures (i.e., dams, deflectors) and other actions (i.e., substrate development, bank cover treatments). These river and stream-based restoration actions are also discussed in relation to the enhancement of associated fish habitats.

Liming of an acidified waterway is a habitat enhancement/restoration action that can be used to mitigate oil injuries to fish. Watt (1986) describes a small liming program established to reduce the effects of acidity on the salmon populations that inhabit several rivers in Nova Scotia. Chemical transportation on the rivers has caused the pH to decline. The restoration action presented as technically feasible in this situation is the addition of limestone to the rivers to counteract the acidic contamination. This same action can also be used on streams and lakes with low pH levels. In addition to describing the liming process, the expected benefits from the liming program are discussed.

2.3.2.3 Technical Feasibility of Restoration Actions

The following sections discuss the technical feasibility of fishery restoration actions for fish populations injured by oil discharges and associated contamination.

2.3.2.3.1 Natural Recovery

Monitoring of natural recovery is always feasible. See Chapter 3 for a discussion of recovery.

2.3.2.3.2 Restocking/Replacement

See Section 3.3 for a description of various research on this action.

Availability of Services, Materials, and Equipment

Only certain species of fish are readily available for restocking purposes from private, tribal, and public hatcheries. These hatcheries usually concentrate on growing important game fish species (i.e., trout, salmon). However, less popular, non-game species are raised on a smaller scale (Nelson et al., 1978). The fish species that are currently available for restocking are presented in Exhibit 2.18 (American Fisheries Society, 1992). The number of fish available for each species and the geographical distribution of the hatcheries are not determinable.

Special equipment (e.g., insulated tank truck with mechanical refrigeration) may need to be rented, leased, or acquired to effectively transport the fish from a hatchery to the point of release (Nelson et al., 1978). A similar type of truck was used to transport the fish from the lake trout hatcheries to the stocking sites in Lake Superior (Great Lakes Fishery Commission, 1987). The fish were then released through pipes connected to the tanks. It is important that the outlet of these pipes or hoses are placed below the surface of the water to reduce the stress on the fish (Smith et al., 1990b).

Constraints

Proper acclimation of the fish between the transporting tank and the point of release is necessary for good survival. Water from the restocking area is slowly pumped into the transportation tank while the transporting water is slowly let out. This acclimation process to temperature, pH, alkalinity, hardness, and salinity alleviates significant stress to the fish. The difference in temperature between the two water types is the prime determinant of the time required. This process should be executed at a rate of at least one hour for every four degrees Celsius in temperature difference (Smith et al., 1990b).

Another consideration for the availability of fish for restocking is the location of the restoration site in relation to the nearest hatchery that raises the same type of fish needed for restocking. If the types of fish injured by contamination are not currently being raised in a hatchery or the nearest hatchery is beyond feasible transportation distance, then a hatchery could be created to raise the type of species needed to restore the injured fish habitat. Two primary limitations exist for creating a new hatchery, adequate clean water supply that is between 50 and 80 degrees Fahrenheit (i.e., depending on whether the species prefers cold or warm water), and the ability to meet current wastewater effluent standards (Nelson et al., 1978).

Exhibit 2.18 Freshwater and marine species available from hatcheries.

Order	Family	Species
ACIPENSERIFORMES	Acipenseridae (Sturgeons)	Acipenser oxyrhynchus (Atlantic sturgeon)
		Acipenser medirostris (Green sturgeon)
		Acipenser fulvescens (Lake sturgeon)
		Scaphirhynchus albus (Pallid sturgeon)
		Acipenser brevirostrum (Shortnose sturgeon)
		Scaphirhynchus platorynchus (Shovelnose sturgeon)
		Acipenser transmontanus (White sturgeon)
	Polyodontidae (Padddlefish)	Polyodon spathula (Paddlefish)
LEPISOSTEIFORMES	Lepisosteidae (Gars)	Atractosteus spatual (Alligator gar)
		Lepisosteus platyrhincus (Florida gar)
		Lepisosteus osseus (Longnose gar)
		Lepisosteus platostomus (Shortnose gar)
		Lepisosteus oculatus (Spotted gar)
AMIIFORMES	Amiidae (Bowfin)	Amia calva (Bowfin)
ANGUILLIFORMES	Anguillidae (Freshwater eels)	Anguilla rostrata (American eel)
OSTEOGLOSSIFORMES	Hiodonidae (Mooneyes)	Hiodon alosoides (Goldeye)
		Hiodon tergisus (Moodeye)
SALMONIFORMES	Salmonidae (Trouts)	Salmo salar (Atlantic salmon)
		Oncorhynchus tshawytscha (Chinook salmon)
		Oncorhynchus keta (Chum salmon)
		Oncorhynchus kisutch (Coho salmon)
		Oncorhynchus gorbuscha (Pink salmon)
		Oncorhynchus nerka (Sockeye salmon)
		Salvelinus alpinus (Arctic char)
		Thymallus articus (Arctic grayling)
		Coregonus spp. (Cisco)
		Salvelinus fontinalis (Brook trout)
		Salmo trutta(Brown trout)
		Oncorhynchus clarki (Cutthroat trout)
		Salvelinus namaycush (Lake trout)
		Prosopium spp. (Whitefish)
		Oncorhynchus mykiss (Rainbow trout)
	Umbridae (Mudminnows)	Umbra spp. (Mudminnow)
	Esocidae (Pikes)	Esox niger (Chain pickerel)
		Esox americanus vermiculatus (Grass pickerel)
		Esox lucius (Northern pike)
		Esox americanus americanus (Redfin pickerel)
		Esox masquinongy (Muskellunge)
		Esox lucius/masquinongy (Tiger muskellunge)

CYPRINIFORMES	Characidae (Characins)	Astynanax mexicanus (Mexican tetra)
	Cyprinidae (Minnows and Carps)	Cyprinus carpio (Common carp)
		Campostoma spp. (Stoneroller)
		Pimephales promelas (Fathead minnow)
		Notemigonus crysoleucas (Golden shiner)
		Ctenopharyngodon idella (Grass carp)
		Other cyprinids
		Ictiobus cyprinellus (Bigmouth buffalo)
		Ictiobus niger (Black buffalo)
		Ictiobus babalus (Smallmouth buffalo)
		Hypentelium etowanum (Alabama hog sucker)
		Moxostoma duquesnei (Black redhorse)
		Moxostoma poecilurim (Blacktail redhorse)
		Cycleptus elongatus (Blue sucker)
		Erimyzon oblongus (Creek chubsucker)
		Moxostoma erythrurum (Golden redhorse)
		Erimyzom sucetta (Lake chubsucker)
		Catostomus catostomus (Longnosre sucker)
		Catostomus platrhynchus (Mountain sucker)
		Hypentelium nigricans (Northern hog sucker)
		Moxostoma macrolepidotum (Shorthead redhorse)
		Moxostoma anisurum (Silver redhorse)
		Catostomus commersoni (White sucker)
		Carpiodes cyprinus (Quillback)
		Carpiodes carpio (River carpsucker)
SILURIFORMES	Ictaluridae (Freshwater catfish)	Ictalurus furcatus (Blue catfish)
		Ictalurus punctatus (Channel catfish)
		Pylodictus olivaris (Flathead catfish)
		Ictalurus catus (White catfish)
		Ictalurus melas (Black bullhead)
		Ictalurus nebulosus (Brown bullhead)
		Ictalurus platycephalus (Flat bullheadd)
		Norurus spp. (Maddtoms)
		Ictalurus natalis (Yellow bullhead)
		Aphredoderus sayanus (Pirate perch)
		Percopsis Omiscomaycus (Trout-perch)
ANTHERINIFORMES	Cyprinidonitae (Killifishes)	Fundulus spp. (Killifish, topminnows, studfish)
	Poeciliidae (Livebearers)	Gambusia affinis (Mosquitofish)
	Atheriniddae (Silversides)	Labidesthes sicculus (Brook silverside)
		Menidia beryllina (Inland silverside)
		Menidia extensa (Waccamaw silverside)
GASTEROSTEIFORMES	Gasterosteidae (Sticklebacks)	Apeltes quaddracus (Fourspine stickleback)
		Gasterosteus aculeatus (Threespine stickleback)
PERCIFORMES	Percichthyidae (Temperate basses)	Morone saxatilis (Striped bass)
		Morone chrysops (white bass)
		Morone mississippiensis (Yellow bass)
		Monone americana (White perch)
	Centrarchiddae (Sunfishes)	Micropterus salmoides (Largemouth bass)
		Micropterus coosae (Redeye bass)
		Micropterus punctulatus (Spotted bass)

		Micropterus dolomieui (Smallmouth bass)
		Pomoxis nigromaculatus (Blackcrappie)
		Pomoxis annularis (White crappie)
		Felassoma zonatum (Banded pygmy sunfish)
		Enneacanthus obesus (Banded sunfish)
		Lepomis macrochirus (Bluegill)
		Enneacanthus gloriosus (Bluespotted sunfish)
		Lepomis marginatus (Dollar sunfish)
		Centrarchus macropterus (Flier)
		Lepomis cyanellus (Green sunfish)
		Lepomis megalotis (Longear sunfish)
		Lepomis humilis (Orangespotted sunfish)
		Lepomis gibbosus (Pumpkinseed)
		Lepomis auritus (Redbreast sunfish)
		Lepomis microlophus (Redear sunfish)
		Ambloplites rupestris (Rock bass)
		Amblopolites ariommus (Shadow bass)
		Lepomis punctatus (Spotted sunfish)
		Lepomis gulosus (Warmouth)
		Perca flavenscens (Yellow perch)
		Etheostoma spp.; Percina spp. (Darters)
		Stizostedion canadense (Sauger)
		Stizostedion vitreum vitreum (Walleye)
		Aplodinotus grunniens (Freshwater drum)
	Cichlidae (Cichlids)	Tilapia melanotheron (Blackchin tilapia)
		Tilapia aurea (Blue tilapia)
		Tilapia mossambica (Mozambique tilapia)
		Tilapia zilli (Redbelly tilapia)
		Tilapia mariae (Spotted tilapia)
	Cottidae (Sculpins)	Cottus spp. (Sculpin)
Source: American Fisheries Society, 1990.		

Future Restoration Actions

In some cases, mortality among restocked fish can be significant. Monitoring the restoration site for the initial two or three days after restocking is important to evaluate survival (Nelson et al., 1978; Smith et al., 1990b). If the mortality rate is higher than 5 percent, then additional restocking is necessary (Smith et al., 1990b).

2.3.2.3.3 Habitat Restoration and Enhancement

See Section 3.3 for a more detailed description of this action. Also, the habitat restoration actions in Section 2.2 apply here as well.

Availability of Services, Materials and Equipment

For reliable information on artificial reef design, development, materials, etc., Duedall and Champ (1991) recommend contacting the Artificial Reef Development Center, a branch of the Sport Fishing Institute. In addition, new developments are discussed periodically at several national and international conferences focused on artificial reefs. Other groups participating actively in artificial reef programs include the federal government, state governments (e.g., California, Florida, North Carolina, Washington), local governments, academic entities, and private companies. NMFS provides guidance through the National Artificial Reef Plan (Duedall and Champ, 1991).

The materials that are feasible to use in the formation of artificial reefs are immeasurable. The type of material can range from readily available items (e.g., old automobile tires) to reef structures constructed specifically for this purpose (e.g., plastic resin formed into a cone shape). Following are several examples of materials used to construct the artificial reefs discussed in the literature:

- According to Duedall and Champ (1991), common materials used internationally for artificial reef construction include aircraft; automobiles, buses, and trolleys, bamboo and bamboo combined with tires; baled garbage; bridges; concrete blocks; construction rubble (concrete debris such as culverts, pile cutoffs); engines; fiberglass and reinforced plastic; freight trains and wheels; metal (primarily steel and iron); quarry rock (i.e., granite, sandstone, limestone); offshore oil and gas platforms; polypropylene rope and cable; polyvinyl chloride piping; refrigerators, stoves, water heaters, and washing machines; ships and boats; stabilized ash (i.e., coal ash, oil ash, incineration ash) in a concrete matrix; sinks and toilets; tires; weapons of war; and wood, trees, and brush. In the U.S., reef engineers are now discouraged from using trash and debris in their designs because of the public perception of dumping instead of reef building and the possibility of contamination and pollution from the debris. Instead, many designs are created with various configurations and combinations of concrete, quarry rock, wood, and tires;

- Feigenbaum et al. (1989) experimented with five reef structure types, unballasted tire bundles, high surface area tires, tires embedded in concrete, concrete igloos, and concrete pipe pyramids. Hueckel et al. (1989) used quarry rock to construct the rocky habitat artificial reefs because of its durable qualities and the large quantities readily available in Washington. The artificial reef development program, discussed by Prince and Maughan (1978), used triangle tire units for the reefs;

- Nelson et al. (1978) examined studies that used brush shelters, tire shelters, and other fish shelters (e.g., rubble, concrete pipe, cement blocks, quarry stone, old cars) for artificial reefs. One experiment in California consisted of creating artificial kelp beds to enhance fishery habitats by placing plastic strips weighted on one end into an appropriate habitat;

- The eight manufactured artificial reef structures evaluated by Bell et al. (1989) consisted of steel-reinforced concrete pipes with holes, larger steel-reinforced concrete pipes, polyolefin plastic cones, polyolefin plastic hemispheres, structural steel cubes, modified structural steel cubes with plastic mesh, modified concrete and PVC docks, and tires embedded in concrete;

- The artificial reef proposed for offsite habitat mitigation of a landfill development project for the Port of Long Beach, described by Knatz (1987), consisted of contaminant-free concrete, rubble, and riprap rock. The rocks were a minimum of 1 foot in diameter and were placed into piles 10 feet high; and

- Obsolete petroleum platforms are another source for artificial reef structure material. This process of converting an unused platform into an artificial reef structure, instead of destroying it, is the rigs-to-reefs concept (Iudicello, 1989; McGurrin and Fedler, 1989).

Similar to artificial reefs, which are usually placed in lakes, oceans, or bays, artificial stream structures can be constructed from various types of material. The artificial stream structures evaluated and studied by Frissell and Nawa (1992) included lateral log deflectors, diagonal log deflectors, cross-stream log weirs, multiple-log structures, cabled natural woody debris jams, and single and clustered boulders. One proposed *Exxon Valdez* restoration project, directed at the restoration of chum salmon habitat and population, involves the installation of instream structures consisting of large boulders and logs (Exxon Valdez Oil Spill Trustees, 1992a).

Nelson et al. (1978) evaluate several types of artificial stream structures used to enhance fish habitats through diversification. Current deflectors are installed in a stream to control and regulate stream flows to benefit fish habitats and decrease bank erosion. There are many current deflector shapes including the triangular wing, peninsular wing, and peninsular wing with chute. These deflectors are constructed from common, natural materials, such as logs, rock, or gabions (wire baskets filled with rocks).

Wesche (1985) and Gore et al. (1988) recommend several types of artificial stream structures that will potentially enhance fishery habitats. These structures include: current deflectors constructed from various formations of logs, rocks, gabions, and wire mesh; low-profile dams constructed from rocks, boulders, logs, and gabions; and single or groups of boulders. The introduction of beaver populations into a suitable habitat is one natural action recommended for the establishment of a low-profile dam structure.

The fish passageways constructed for the Northwest hydroelectric dam-related program consisted of installation of fish ladders and placement of submerged screens blocking the entrance to the turbines. The screens encourage the fish to travel through a chute where the fish will either be released into the river below the dam or loaded onto a barge and released further down the river. During the time period prior to construction of mechanical passageways, two methods of allowing the fish to bypass the dam are to intentionally discharge water over the edge of the dam or to raise the emergency headgates on the dam. Of course, these methods only work for fish migrating toward the ocean. Fish ladders allow movement back up the river (Smallowitz, 1989).

Nelson et al. (1978) evaluate several fish passageway improvement actions, including trap and haul systems, fishways, conduits, culverts, and turbine bypasses. The trap and haul systems are developed to transport migrating fish species through an obstruction (e.g., hydroelectric dam), typically upstream. The fishways evaluated include non-mechanical methods of allowing the fish to swim upstream, such as fish ladders or fish passes. These actions were primarily used to improve the passageway of fish through or around dams. Three types of fish ladders are evaluated, including pool/weir, pool/orifice, and vertical slot ladders. Conduits and culverts are structures established as bypass systems, for both upstream and downstream-migrating fish, around dams and other obstructions. Turbine bypasses are constructed to deter fish travelling downstream from passing through the hydroelectric turbines of dams.

One proposed method to facilitate the restoration of pink salmon populations injured by the *Exxon Valdez* oil discharge is the installation of several fish passageway barrier bypasses on streams important to the pink salmon fish species. The bypasses would consist of channels and steeppasses, which would be anchored with cable for stability. Water diversion structures constructed from gabions reinforced with steel pipe would force water through the channels and steeppasses (Exxon Valdez Oil Spill Trustees, 1992a).

During the construction and installation phases of artificial reef development, special equipment (e.g., crane) may need to be rented or leased. The Smith Mountain Lake artificial reef development program, discussed by Prince and Maughan (1978), used the following pieces of common equipment to construct and deploy the artificial reef structures, crane, barge, tug boat, forklift, tractor, and tractor trailer.

Bell et al. (1989) provide a list of equipment used to deploy the eight types of manufactured artificial reefs evaluated in their study. The reef units were either dropped by a forklift, pushed or rolled in by hand, sunk by swimmers, or sunk and anchored by divers. The structures were deployed from common vessels such as a 30.5 meter research vessel, a 12.2 meter sport fishing boat, and a 33 meter deck-barge and tugboat. In two cases, the structures were towed by a 15.2 meter research vessel. To load the structures on the vessels, a 0.9 metric ton forklift, a 1.8 metric ton forklift, and a 9.1 metric ton crane were used. For the structures constructed from plastic, no additional equipment was needed to load them onto the deployment vessel.

The equipment required for the methods of distribution of limestone examined for the Nova Scotia river liming project includes trucks, tractors, boats, helicopters, or airplanes capable of distributing limestone, and various road construction equipment (Watt, 1986).

Constraints

Although many different types of materials may be used to construct an artificial reef, there are several factors to consider, besides availability and short-term cost effectiveness, when selecting appropriate material. Hueckel et al. (1989) stress the importance of using durable material for the construction of artificial reefs. Fragile substances will deteriorate at a rate that will require frequent repairs or replacement, thus causing unnecessary disturbance to the habitat. The ideal situation is to use the most durable material that is also readily available and cost effective, such as the quarry rock they used to mitigate a rocky subtidal habitat.

Another consideration discussed by Hueckel et al. (1989) is the selection of an appropriate reef site. Their major concern was disturbance from vessel traffic and commercial net fisheries.

Feigenbaum et al. (1989) indicate a variation on structural stability and mobility considerations based on the location of the reef. Their study found that reefs placed in coastal waters were less stable and more mobile in coastal waters than in protected or semi-protected waters (e.g., the Chesapeake Bay), mostly due to storm activity.

Duedall and Champ (1991) provide a comprehensive list of other factors to consider before selecting an artificial reef site. These considerations include accessibility to and distance from shore; availability of reef-building materials; biological characteristics of the site and adjacent areas; depth of photic zone; detriments (i.e., vessel lanes); ease of reef deployment; liability, insurance, and permit requirements; oceanographic characteristics, currents, and wave conditions; projected uses and benefits of the site, both economic and recreational; sedimentation rate; target species; turbidity; and weather and storms.

McGurrin and Fedler (1989) provide several issues to consider during the siting phase of an artificial reef in the rigs-to-reefs program. These considerations follow general coastal zone mapping procedures and include assessment of the current marine recreational fishing industry, location of the important recreational fishing zones, and elimination of the areas with potential interference to the artificial reef activities (i.e., shipping lanes, military warning zones, and marine sanctuaries).

Artificial stream structures are not recommended for installation in streams where the gradient exceeds 3 percent or where the stream flow fluctuates substantially, according to the U.S. Forest Service (Nelson et al., 1978). The exception to this guideline is the low-profile dam structure. Dams can be effective up to a 20 percent gradient level. In addition, current deflectors and dams should not protrude more than 0.3 meters above the low-flow level. The deflectors should also be angled downstream at about a 45 degree angle from the current (Wesche, 1985).

According to the U.S. Forest Service, it is recommended that brush shelters, which are constructed in various forms from brush and trees, be placed in an area with approximately four meters of water and weed-free, hard bottoms. If more than one shelter, or artificial reef, is installed in an area, they should be separated by at least 45 meters (Nelson et al., 1978).

It is also recommended that the design for a fish ladder include drops no longer than 30 centimeters. The orifices should be no larger than 1.2 square meters on the pool and orifice ladder. The overall vertical height of any fish ladder should be 30 meters or less (Nelson et al., 1978).

There are operational limitations related to many of the fish passageway improvement methods. For all fish passageways, the opening must be easily accessible and attractive to fish. An operational constraint related to the trap and haul system, used to transport fish upstream, is the potential for injury of the fish. In some cases, the trap and haul system is the combination of a fish ladder and hopper shaft. However, this system could also consist of trapping the fish in a barge, transporting them to a new location, and releasing the fish. The latter method has a higher potential for injury to the fish. Debris accumulates easily in the pool/weir or pool/orifice fish ladders. These ladders also can not tolerate large shifts in water levels. The vertical slot ladder does not have the debris problem works more effectively when the water levels are equal at both ends (Nelson et al., 1978).

2.3.2.3.4 Modification of Management Practices

Intensified monitoring and management of fishery stocks (especially coastal cutthroat trout, pink salmon, sockeye salmon, Pacific herring, rockfish, and Dolly Varden) was proposed for several related restoration projects following the *Exxon Valdez* oil discharge. This increase in fishery management typically includes shifting recreational and commercial fishing efforts away from injured stocks to alternative sites that were not affected by the discharge (Exxon Valdez Oil Spill Trustees, 1992a,b).

Prior to establishing management policies related to fisheries use, a database with population, size, and other vital information about each fishery at various sites should be developed and maintained. Acquisition of these data would require intensive field work (Exxon Valdez Oil Spill Trustees, 1992a).

2.3.2.3.5 Habitat Protection and Acquisition

Under consideration by the Exxon Valdez Oil Spill Trustees (1992b) are two fishery habitat protection and acquisition strategies. The first plan includes the designation of specific injured regions as protected marine habitat areas (i.e., national marine sanctuaries, marine parks). The second proposal under consideration is the acquisition of private areas for the purpose of recreational fishing. This would alleviate the pressure on recovering sport fishing stocks. The applicability of such alternatives is highly site-specific and depends on the availability of appropriate lands in a particular region.

2.3.3 Reptiles

There exist three technically-feasible actions for restoring injured reptile populations. These actions include:

- Natural Recovery;
- Restocking/Replacement; and
- Protection of Nest Sites.

Protection of nest sites requires the development and implementation of measures to secure and preserve the sites from predators, human interference, beach erosion, pollution, and other forms of perturbation.

2.3.3.1 Oil Related Literature

The text "Restoration of Habitats Impacted by Oil Spills," edited by Cairns and Buikema (1984), includes information on the restoration of sea turtles injured or destroyed by an oil discharge. The suggested restoration method is restocking, using an alternate site if full restoration of the discharge site is unattainable, with hatchery-reared turtles.

2.3.3.2 Non-oil Related Literature

A report developed by International Animal Exchange, Inc. (1992), an international company specializing in animal procurement and relocation (for zoos and aquariums), provides the availability and cost estimates to deliver live wildlife specimens from captive sources for the purpose of reintroduction to the wild in U.S. territories and the cost estimates to obtain, transport, and acclimate wildlife specimens from the wild. The availability of relocating wild species from other locations to the affected area depends on the terms of the permit acquired for such an activity. Additional information on the actual process of relocation or replenishment of a wildlife population and the predicted survival rates from such activities was obtained through personal communication (Hunt, 1993).

Two similar studies, prepared by the Loggerhead/Green Turtle Recovery Team for the National Marine Fisheries Service (NMFS) and the Southeast Region of the U.S. Fish and Wildlife Service, describe the proposed recovery plans for the Loggerhead and Atlantic Green turtles (NMFS, 1990a,b). In addition to describing the objectives and outline of the recovery plans, these studies also describe the population characteristics, distribution, and size, threats to the turtle nesting and marine environments, and conservation accomplishments in the nesting and marine environments. Sea turtle restoration plans are discussed fully in Section 3.3.3.

2.3.3.3 Technical Feasibility of Restoration Actions

The following subsections discuss the technical feasibility of three actions for reptile restoration.

2.3.3.3.1 Natural Recovery

Monitoring of natural recovery is technically feasible. See Chapter 3 for discussion of recovery.

2.3.3.3.2 Restocking/Replacement

Restocking entails either relocating the necessary species to the restoration area from another location or supplementing the injured reptile population with captive raised species. This restocking/replacement action is evaluated below.

Availability of Services, Materials, and Equipment

In addition to the International Animal Exchange, Inc. described above, there are several companies that conduct similar animal procurement and relocation operations. All of these companies are members of the American Association of Zoological Parks and Aquariums (AAZPA). The names, addresses, and telephone numbers of these companies are listed below (AAZPA, 1990):

- Fauna Research & Development, Inc.
  Bard Avenue
  Red Hook, NY 12571
  (914) 758-2549

- International Animal Exchange, Inc.
  E. Nine Mile Road
  Ferndale, MI 48220
  (313) 398-6533

- International Zoological Distributors
  Herve Beaudry
  Laval, P., Quebec, Canada H7E 2X6
  (514) 661-8081

- Lamkin Wildlife Company
  Box 5843
  Amarillo, TX 79117
  (806) 383-4085

- Nelson's Twin Oaks Farm
  Bethany Road
  Alpharetta, GA 30201
  (404) 475-4918

- Earl Tatum
  Pleasant Ridge Drive
  Eureka Springs, AR 72632
  (501) 253-9696

- Zeehandelaar, Inc.
  Sickles Avenue
  New Rochelle, NY 10801
  (914) 636-2096

- Zoological Animal Exchange
  Route 610, Box 164
  Natural Bridge, VA 24578
  291-3205

Some of these companies have experience in all types of wildlife, while others concentrate on only a few types of species. Therefore, during an actual restoration project where many different species are involved, it may be necessary to acquire the services of more than one company.

These firms have expertise in the process of wildlife acclimation and transportation. They also typically own or have access to the proper equipment necessary for successful transportation of the species to the restoration site and acclimation of the species into their new habitat (Hunt, 1993).

The estimated quantities of captive raised or intensively managed reptiles available for restocking purposes are provided in Exhibit 2.19. If the required number of animals are not available from captivity, then the remainder could be relocated from the wild. Relocation of reptiles is typically not feasible or permitted in the United States (Hunt, 1993) and consideration of impacts on the donor population must be made.

Constraints

The primary operational constraints associated with restocking reptile populations are logistics (e.g., the population being restocked is difficult to reach by humans), procurement of required permits, climate, finance, and public interference (Hunt, 1993).

Prior to any restocking or relocating activities, the animal supplier should conduct an in depth study of the species involved. An optimum age for each particular species should be determined. Typically, a juvenile of the species is selected as the most adaptable lifestage. The juvenile is usually the least susceptible to stress from translocation because species at this age are psychologically and physically more adaptable. Restocking, translocating a species from captivity to the wild, has a higher impact on the stress level of an animal than relocating the species from one wild habitat to another (Hunt, 1993).

Future Restoration Actions

The period of time a newly acclimated population is monitored following a relocation or restocking activity depends on the circumstances of the situation. For some populations (e.g., a sea turtle or migratory bird population), monitoring is difficult or not feasible. In other cases, where the populations are gradually acclimated to the wild, monitoring and support of the population is required throughout the transition period sometimes continuing for several generations (Hunt, 1993).

It is expected that some mortalities will occur after translocation of a population. These mortality rates, however, are difficult to estimate for even generic classes of wildlife species. The expected mortality rates include many factors that are specific to the situation and species involved. Any mortalities experienced after a relocation or restocking effort are not covered by the service provider. In a few cases, third party insurance was obtained to meet specific contractual requirements, but this is not standard practice (Hunt, 1993).

Exhibit 2.19 Availability of captive raised reptiles for restocking purposes.

Family	Species	Number of Reptiles Available
Cheloniidae	Atlantic loggerhead turtle	0
	Pacific loggerhead turtle	0
	Atlantic ridley turtle	0
	Pacific ridley turtle	0
Dermochelyidae	Atlantic leatherback turtle	0
	Pacific leatherback turtle	0
Crocodylidae alligatorinae	American alligator	5,000

Source: International Animal Exchange, 1992.

2.3.3.3.3 Protection of Nest Sites

There are many measures recommended in the recovery plans of the Atlantic Green and Loggerhead turtles, that are technically feasible to implement for protection of the nesting habitats of sea turtles (NMFS, 1990a,b). These measures include:

- Developing predator control programs;
- Controlling beach nourishment process;
- Preventing degradation of nesting sites from beach/shoreline erosion control measures;
- Enhancing nesting habitats;
- Acquiring/protecting important nesting beaches;
- Removing exotic vegetation; and
- Protecting nesting habitats from human interference (e.g., artificial lights, foot/vehicular traffic, poaching) through ordinances, regulations, and educational materials.

Constraints

The preferable method of protecting nest habitats involves a minimum of disturbance to the nesting population with a maximum of effectiveness in preventing injury of the nest sites. Nests are relocated only in situations where no other alternatives exist. Artificial incubation of turtle eggs is typically avoided. Most government agencies strive for implementing protective measures that yield a 50 percent hatch rate (NMFS, 1990a,b).

A majority of the protection measures listed above require a high level of cooperation between federal, state, and local officials. Effective monitoring of each situation prior to the implementation of protection measures is an essential phase of the process. Government agencies are needed to implement the control measures of the beach nourishment and beach/shoreline erosion control processes and develop and enforce ordinances and regulations that control human interference with the nest habitats. The involvement of government agencies and non-profit organizations is also necessary for the development and distribution of educational material to increase the public awareness of injury to the nesting sites which results from certain human activities.

2.3.4 Birds

Five general alternatives for restoring injured bird populations include:

- Natural Recovery;
- Restocking/Replacement;
- Habitat Restoration and Enhancement;
- Modification of Management Practices; and
- Habitat Protection and Acquisition.

2.3.4.1 Oil Related Literature

The "1993 Draft Work Plan" and comprehensive 1992 preliminary restoration plan for the *Exxon Valdez*, described in detail in Section 2.3.2.1, describe several restoration alternatives for bird populations affected by the oil discharge (Exxon Valdez Oil Spill Trustees, 1992a, b). These alternatives include reducing human disturbance at bird colonies, controlling harvest of sea ducks, and eliminating continuous oil contamination of prey substrates.

2.3.4.2 Non-oil Related Literature

As described in Section 2.3.3.2, International Animal Exchange, Inc. (1992) developed a report that provides availability levels for stocking of various wildlife species. A majority of the species included are birds. The availability of captive-raised birds and the technical feasibility of restocking are discussed below.

2.3.4.3 Technical Feasibility of Restoration Actions

The following subsections discuss the technical feasibility of restoration actions for bird populations.

2.3.4.3.1 Natural Recovery

Monitoring of natural recovery is technically feasible. See Chapter 3 for discussion of recovery.

2.3.4.3.2 Restocking/Replacement

A discussion on the technical feasibility of the wildlife restocking/replacement restoration action is located in Section 2.3.3.3.2.

Availability of Services, Materials, and Equipment

Refer to this subheading in Section 2.3.3.3.2. for a discussion on the availability of restocking/replacement services for wildlife restoration purposes. The estimated quantities of captive raised birds available for restocking purposes are provided in Exhibit 2.20.

There are several significant considerations associated with the relocation of birds. In addition to the issues referred to in Section 2.3.3.3.2, the restoration facilitators need to ensure that the species taken from one population and relocated to a new site do not cause adverse effects on the original population. Although it varies by species, bird populations can normally withstand a loss of 2 to 6 percent (Hunt, 1993).

Constraints

Refer to this subheading in Section 2.3.3.3.2. for a discussion on the various operational constraints related to restocking.

Future Restoration Actions

Refer to this subheading in Section 2.3.3.3.2. for a discussion on the need and capability of future restoration actions after restocking.

2.3.4.3.3 Habitat Restoration and Enhancement

Nelson et al. (1978) recommend two feasible types of bird habitat restoration and enhancement actions: construction of artificial nesting structures and man-made nesting islands. The nesting structures are appropriate for ducks, geese, cormorants, eagles, ospreys, herons, and other species. The nesting islands are suitable for migrating bird species and nesting waterfowl and shorebirds.

Availability of Services, Materials, and Equipment

The nesting structures are typically constructed from wood or metal, although wood is preferable. Nesting islands are developed from both gravel and dredge spoil. Nest enclosures on the islands are constructed from natural materials (e.g., driftwood). Nesting materials, which should be replaced annually, can consist of wild hay, straw, or wood shavings (Nelson et al., 1978).

Exhibit 2.20 Availability of captive raised birds for restocking purposes.

Family	Species	Number of Birds Available
Gaviidae	Common loon	0
Podicipedidae	Horned grebe	0
	Red-necked grebe	0
Domedeidae	Laysan albatross	0
	Black-forested albatross	0
Procellariidae	Northern fulmar	0
	Japanese petrel	0
	Hawaiian petrel	0
	Greater shearwater	0
	Sooty shearwater	0
	Manx shearwater	0
	Short-tailed shearwater	0
Hydrobatidae	Least storm petrel	0
	White-vented storm petrel	0
	Band-rumped storm petrel	0
	Ashy storm petrel	0
	Ringed storm petrel	0
	Leaches storm petrel	0
Pelecanidae	American white pelican	10
	Brown pelican	300
Sulidae	Northern gannet	0
	Blue-footed booby	0
Phalacrocoracidae	Double crested cormorant	0
	SW Double-created cormorant	0
	NW Double-created comorant	0
	Common (great) cormorant	400
	Northern great cormorant	0
	Olivaceous cormorant	0
Ardeidae	American bittern	0
	Great blue heron	10
	Green heron	0
	Tricolored heron	0
	Black-crowned night heron	0
	Night heron	0
	Yellow-crowned night heron	0
	Cattle egret	900

Family	Species	Number of Birds Available
	Snowy egret	100
Threskiornithidae	American white ibis	100
	Scarlet ibis	100
	Bare-faced ibis	0
	White-faced ibis	0
	Glossy ibis	800
	Roseate spoonbill	40
Phoenicopteridae	American flamingo	100
Anatidae	White-fronted goose	30
	Tule goose	0
	Graying goose	30
	Snow goose	100
	Greater snow goose	0
	Lesser snow goose	50
	Emperor goose	30
	Ross goose	30
	Lawrences brant goose	0
	Pacific brant goose	0
	Canada goose (generic)	1,000
	Whistling swan	0
	Trumpeter swan	240
	Duck (most species; generic)	500
Accipitridae	Hawk/Eagle (most species; generic)	0
Gruidae	Whooping crane	0
	Sandhill crane	50
	Lesser sandhill crane	50
	Florida sandhill crane	50
	Mississippi sandhill crane	0
	Canadian sandhill crane	0
	Greater sandhill crane	0
Aramidae	Limpkin	0
Rallidae	Rail/Coot (most species; generic)	0
Haematopodidae	American oystercatcher	0
Recurvirostridae	Hawaiian stilt	0
	Black-winged stilt	0
	Black-necked stilt	0
	American avocet	0
Charadrilidae	Lesser golden plover	0
	Black-bellied plover	0

Family	Species	Number of Birds Available
Scolopacidae	Spotted sandpiper	0
	Upland sandpiper	0
	Willet	0
	Wandering tattler	0
	Godwit	0
	Long-billed curlew	0
	Lesser yellowlegs	0
	Greater yellowlegs	0
	Solitary sandpiper	0
	Black turnstone	0
	Andean snipe	0
Laridae	Gull/tern (most species; generic)	0
Alcidae	Puffin (most species; generic)	10

Source: International Animal Exchange, 1992.

Constraints

A significant constraint on the design and siting of both the nest structures and islands is the protection from predators. This can easily be achieved by installing a fence around the site or positioning the nest several feet or more off the ground or water. Another consideration for placement of a nest on or near water is the fluctuation in flow or the flood level of water. This fluctuation should be controlled as much as possible during the nesting season (Nelson et al., 1978).

This restoration action should be considered temporary in most cases. It is designed to provide nesting shelter until more permanent, natural facilities are reestablished in the habitat (Nelson et al., 1978).

2.3.4.3.4 Modification of Management Practices

The Exxon Valdez Oil Spill Trustees have proposed to reduce disturbance to bird colonies (i.e., specifically the common murres) to allow the restoration process to continue free from human disturbance. This includes educating appropriate industries (e.g., commercial fishing) of the methods proposed to reduce disturbance and to establish strict enforcement of the Migratory Bird Treaty Act. Modification of fishing gear (e.g., gillnets) or fishing practices could protect diving seabirds such as marbled murrelets. The Exxon Valdez Trustees are also considering restrictions on the legal harvest of sea ducks by shortening the length of the hunting season and reducing bag limits (Exxon Valdez Oil Spill Trustees, 1992a,b).

In addition to protection from disturbance and hunting as effective management practices for restoration of seabirds, Nur and Ainley (1992) suggest the protection of prey availability through monitoring and controlling fisheries important to the seabird species. The feasibility of this alternative is not documented.

2.3.4.3.5 Habitat Protection and Acquisition

Designating injured bird habitats and implementing and expanding buffer zones are possible actions for habitat protection and acquisition. These actions were recommended by the Exxon Valdez Oil Spill Trustees (1992b) in protecting marine areas, and creating nesting areas for seabirds, sea ducks, and bald eagles.

2.3.5 Mammals

Five actions for restoring injured mammal populations are:

- Natural Recovery;
- Restocking/Replacement;
- Habitat Restoration and Enhancement;
- Modification of Management Practices; and
- Habitat Protection and Acquisition.

2.3.5.1 Oil Related Literature

The "1993 Draft Work Plan" and the comprehensive 1992 preliminary restoration plan for the *Exxon Valdez* suggest several restoration actions for mammal populations affected by the oil discharge (Exxon Valdez Oil Spill Trustees, 1992a and 1992b). These actions include reducing human disturbance at marine mammal haul-out sites, controlling harvest of specific marine and terrestrial mammals, and eliminating continuous oil contamination of prey substrates.

Cairns and Buikema (1984) provide information on the restoration of marine mammals injured by an oil discharge. One restoration action, suggested for implementation, is restocking the restored habitat or an alternative site if full restoration of the discharge site is unattainable.

2.3.5.2 Non-oil Related Literature

As described in Section 2.3.3.2., International Animal Exchange, Inc. (1992) reports the availability of various wildlife species. Several of the species included are marine mammals. The availability of captive-raised mammals and technical feasibility of successfully replenishing an affected mammal population is discussed in detail in the following discussion.

2.3.5.3 Technical Feasibility of Restoration Actions

The following subsections discuss the technical feasibility of restoration actions for mammals.

2.3.5.3.1 Natural Recovery

Monitoring of natural recovery is technically feasible. See Chapter 3 for a discussion of recovery.

2.3.5.3.2 Restocking/Replacement

A discussion on the technical feasibility of the wildlife restocking/replacement restoration action is located in Section 2.3.3.3.2.

<u>Availability of Services, Materials, and Equipment</u>

Refer to Section 2.3.3.3.2. for a discussion on the availability of restocking/replacement services for wildlife restoration purposes. The estimated quantities of captive raised mammals available for restocking purposes are provided in Exhibit 2.21. The suppliers claim high survival rates of these animals, assuming care and effort is taken as indicated by the costs in Chapter 4.

As mentioned in Section 2.3.4.3.2, wildlife populations can withstand a small decrease without adverse effects. Mammal populations can sustain of a loss of approximately 2 to 4 percent. However, this amount does vary by species (Hunt, 1993).

<u>Constraints</u>

Refer to Section 2.3.3.3.2. for a discussion on the various operational constraints related to restocking.

<u>Future Restoration Actions</u>

Refer to Section 2.3.3.3.2. for a discussion on the need and capability of future restoration action after restocking.

2.3.5.3.3 Habitat Restoration and Enhancement

While provision or improvement of appropriate sites for reproductive or feeding activities could be considered, no documentation of their use is available. General habitat enhancement actions could be conducive to mammal population recovery.

Exhibit 2.21 Availability of captive raised mammals for restocking purposes.

Family	Species	Number of Mammals Available
Cricetidae	Muskrat	0
Delphinide	Killer whale	0
	False killer whale	0
	Northern right-whale dolphin	0
	Saddle back dolphin	0
	Common dolphin	0
	Risso's dolphin	0
	White-sided dolphin	0
	Pacific white-sided dolphin	0
	Gill's bottle-nosed dolphin	0
	Bottle-nosed dolphin	10
	Pacific harbour porpoise	0
	Dall's porpoise	0
Monodontidae	Beluga whale	0
Ursidae	Polar bear	30
Mustelidae	Northern sea ottter	10
	Southern sea otter	0
Otariidae	Northern fur seal	100
	Steller's northern sea lion	0
	California sea lion	50
	Walrus	0
	Bearded seal	0
	Grey seal	20
	Harbor seal	40
	Northern elephant seal	0
	Hawaiian monk seal	0
Trichechidae	Manatee	0

Source: International Animal Exchange, 1992.

2.3.5.3.4 Modification of Management Practices

The Exxon Valdez Oil Spill Trustees are considering the implementation of two modifications to current management practices related to mammals. These actions include the reduction of disturbance at marine mammal haul-out sites and the development of alternative harvest guidelines. The issues related to these actions are discussed in Section 2.3.4.3.4. These management practices would be focused on sea otters, harbor seals, river otters, and brown bears. Many restrictions are already established by the Marine Mammal Protection Act, although stricter enforcement of the above act is proposed (Exxon Valdez Oil Spill Trustees, 1992a,b).

Consideration (in Exxon Valdez restoration planning) is also being given to voluntary use of different fishing gear (pot gear in lieu of long time) for black cod and, possibly, Pacific cod and halibut. This would potentially reduce fishery interactions of killer whales, since killer whales have historically raided long lines in Prince William Sound.

Nur and Ainley (1992) recommend the reduction or elimination of commercial harvesting and incidental killing of pinnipeds and cetaceans as the most effective and feasible modification to management practices.

2.3.5.3.5 Habitat Protection and Acquisition

Similar to fishery habitat protection and acquisition, the Exxon Valdez Oil Spill Trustees also are considering the designation of injured marine mammal habitats as protected marine areas (Exxon Valdez Oil Spill Trustees, 1992b). Refer to Section 2.3.2.3.5 for a complete discussion of this action.

2.4 Replacement Actions

The replacement action is used extensively to compensate for oil discharge-related injuries. Some of which are briefly discussed.

The restoration approach in the OPA restorations favors primary restoration. However, from practical, cost-effectiveness, and scientific perspectives, primary restoration is not the implemented restoration strategy in a number of cases. Compensatory alternatives that do not encompass direct resource or habitat restoration and are often referred to as mitigation. Examples of compensatory actions that have been developed for the mitigation of a habitat through acquisition, service enhancement, or protection/management include:

- Habitat Creation;
- Land Protection;
- Public Access Improvements;
- Other Recreational Facility Improvements;
- Habitat Enhancement;
- Resource Management Practices;
- Pollution Control Activities; and
- Public Awareness Activities.

The relationships between these habitat and resource compensatory actions and the habitat types discussed previously in Sections 2.2 and 2.3 are provided in Exhibit 2.22. There are an exhaustive number of compensatory actions at the habitat-specific level.

The most exhaustive exploration of mitigation strategies, and the one described here, was associated with the *Exxon Valdez* efforts to develop mitigation plans for habitats and services injured by the *Exxon Valdez* discharge. One such document by the Exxon Valdez Oil Spill Trustees (1992a) provides a summary of the habitats and species injured and gives brief descriptions of several potential restoration actions for the resources and/or services affected by the discharge. This report does not represent the final and complete restoration plan for the *Exxon Valdez* discharge, but it does represent the most comprehensive oil discharge restoration plan available and addressed a broader range of alternative than previously undertaken. This plan provides descriptions of several proposed projects related to habitat and resource protection. Another report prepared by the *Exxon Valdez* Oil Spill Trustees (1992c) is the "1993 Draft Work Plan" which summarizes the restoration projects currently under consideration. The projects will be completed through a joint effort from various agencies of the federal government and the state of Alaska

Exhibit 2.22 Compensatory restoration actions.

Habitat Types	Habitat Creation	Land Protection	Public Access Improve-ments	Other Recrea-tional Facility Improvements	Habitat Enhancement (Artificial Reefs, Etc.)	Resource Management Practices	Pollution Control Activities	Public Awareness Activities
Estuarine and Marine Wetlands								
Saltmarsh	🗐	🗐	🗐				🗐	🗐
Mangrove	🗐	🗐	🗐				🗐	🗐
Freshwater Wetlands								
Emergent Wetlands	🗐	🗐	🗐				🗐	🗐
Scrub/Shrub Wetlands	🗐	🗐	🗐				🗐	🗐
Forested Wetlands	🗐	🗐	🗐				🗐	🗐
Bogs and Tundra	🗐	🗐	🗐				🗐	🗐
Vegetated Beds								
Macroalgal Beds	🗐	🗐					🗐	
Seagrass Beds	🗐	🗐					🗐	
Freshwater Aquatic Beds	🗐	🗐					🗐	
Mollusc (Oyster) Reefs	🗐	🗐	🗐				🗐	🗐
Coral Reefs	🗐	🗐	🗐		🗐		🗐	🗐
Estuarine and Marine Intertidal								
Intertidal Rocky Shore		🗐	🗐	🗐			🗐	🗐
Intertidal Cobble-Gravel Beach		🗐	🗐	🗐			🗐	🗐
Intertidal Sand Beach		🗐	🗐	🗐			🗐	🗐
Intertidal Mud Flat		🗐					🗐	
Estuarine and Marine Subtidal								
Rock Bottom							🗐	
Cobble-Gravel/Sand/Silt-								

Habitat Types	Habitat Creation	Land Protection	Public Access Improve-ments	Other Recrea-tional Facility Improvements	Habitat Enhancement (Artificial Reefs, Etc.)	Resource Management Practices	Pollution Control Activities	Public Awareness Activities
Mud Bottom							🗐	
River and Lacustrine Shorelines								
Rock Shore		🗐	🗐	🗐			🗐	🗐
Cobble-Gravel Shore		🗐	🗐	🗐			🗐	🗐
Sand Shore		🗐	🗐	🗐			🗐	🗐
Silt-Mud Shore		🗐					🗐	
Riverrine Bottom								
Rock Bottom							🗐	
Cobble-Gravel/Sand/Silt-Mud Bottom							🗐	
Lacustrine Bottom								
Rock Bottom							🗐	
Cobble-Gravel-Sand/Silt-Mud Bottom							🗐	
Biological Resources								
Shellfish		🗐			🗐	🗐		
Fish		🗐			🗐	🗐		
Reptiles		🗐			🗐	🗐		
Birds		🗐			🗐	🗐		
Mammals		🗐			🗐	🗐		

government. The projects are divided by the following categories for restoration and replacement activities: management action; damage assessment; monitoring; enhancement; technical support; manipulation; habitat protection and acquisition; and land protection.

A prime example of a non-discharge mitigation guidance document is Nelson et al. (1978), a handbook for the U.S. Department of the Interior which summarizes nearly 300 fish and wildlife habitat and population improvement actions. The actions discussed include enhancement actions proven effective during previous dam and reservoir projects or determined to be potentially effective. One section describes the process of land acquisition as a method of habitat restoration and protection.

2.4.1 Technical Feasibility of Replacement Actions

The following paragraphs discuss technically feasible replacement actions and provides examples of each. Again, these mitigation strategies are offered as examples of the range of actions which may be available and is by no means exhaustive.

2.4.1.1 Habitat Creation

After locating a site suitable to sustain a new habitat, actions similar to primary restoration efforts (i.e., grading, planting, supplementary erosion control structures, and sediment removal/replacement) can be used. In general, the strategy should identify a site with the potential of providing an array of critical habitat and natural resource services. This site may be one injured by prior releases of hazardous materials or oil or simply a location in need of environmental enhancement. In some cases the site could even be general land acquired for the specific purpose of habitat creation (e.g., purchase and grading down of upland for saltmarsh creation).

2.4.1.2 Land Protection

Nelson et al. (1978) provides additional information on the protection of wildlife habitats during reservoir and dam projects through land acquisition. They suggest that land can be acquired through purchase, easement, or lease transactions. Based upon these project experiences, a primary constraint is the ability to acquire sufficient land to meet the objectives of the acquisition.

Following the *Exxon Valdez* oil discharge, the need arose for the establishment of protective measures for various non-biological sites. In order to protect the archeological sites and artifacts within the discharge area, which already were vandalized, the Exxon Valdez Oil Spill Trustees implemented a site stewardship program, consisting of a group of local individuals who are to watch remotely-located archeological sites. This program is similar to successful archeological site stewardship programs in Arizona and Texas (Exxon Valdez Oil Spill Trustees, 1992a,b).

The Exxon Valdez Oil Spill trustees are recommending that the oil discharge area be designated a "special management area." This would ensure that any activities requiring permits from the state (e.g., log transfer sites) were not in conflict with the recovery and restoration of injured nataural resources and services. The trustees are also considering that one or more sites should be designated marine protected areas. This designation by the trustee agencies, the Alaska State Legislature, and Congress would help protect the biological natural resources inhabiting the area and preserve the area for recreation and research activities (Exxon Valdez Oil Spill Trustees, 1992b).

Although the State of Alaska and federal governments own a majority of the tidelands that were injured by the discharge, several areas are still owned by municipalities or private individuals. Acquisition by the state of these other areas would provide officially protected habitat for the injured species and create an alternative site for natural resource users. Through easements, property rights, or fee-simple title, the trustees are also investigating the acquisition of upland forests and watersheds within the oil discharge area to ensure protection of vital stream and river areas. Another type of acquisition considered by the trustees is acquiring "inholdings" within existing parks and refuges from willing sellers to further sustain services and provide sufficient refuge for biological natural resources (Exxon Valdez Oil Spill Trustees, 1992b).

2.5 Legal and Regulatory Constraints

Even the most beneficial of restoration actions are subject to a wide variety of legal and regulatory conditions beyond those associated with the damage assessment and restoration planning processes. These influences on restoration actions range from requirements for relatively perfunctory notification, to elaborate multi-agency permitting procedures. As noted in Woodhouse (1979) and Chianelli (1992), these factors have the potential to materially affect the timing and operational feasibility of a project. Because these legal and regulatory factors represent a commonality among many of the restoration actions addressed in this document, they are consolidated into this section.

Exhibit 2.23 Range of federal agency roles potentially affecting implementation of restoration strategy.

FEDERAL AGENCY	SCOPE OF RESOURCE AND HABITAT MANAGEMENT RESPONSIBILITY	LEGISLATIVE AUTHORITY	POTENTIAL PROGRAMS
U.S. Environmental Protection Agency (EPA)	Protect, maintain, restore and enhance water quality	Clean Water Act (P.L. 92-500)). 33 U.S.C. 1251 et seq.	1. National Estuary Program (§320) 2. Discharge permits (NPDES program) (§402)) 3. Oil and hazardous substance spills (§311) 4. Toxic (priority) pollutant and pretreatment program (§307) 5. Nonpoint source control program (§319) 6. Chesapeake Bay program (§117) 7. In-place pollutants (§115) 8. Dredge and fill wetlands program (§404)
	Avoid unreasonable degradation or endangerment of the marine environment or public health	Natioinal Marine Sancturaries Act (P.L. 92-532), 33 U.S.C., 1401 et seq., as amended by the Ocean Dumping Ban Act of 1988 (P.L. 100-688)	1. Site designation of ocean dumpsites for wastes and dredged material [§102(c)] 2. Veto of U.S. Army Corps of Engineers (USACOE) permits for dredged material ocean dumping (§103)
	Regulate pesticide chemicals	Federal Insecticide, Fungicide, and Rodenticide Act (P.L. 92-516), 7. U.S.C. 136 et seq.	Setting of action levels of tolerances for unavoidable pesticide contaminants in fish and shellfish (Food, Drug and Cosmetic Act, §408)
U.S. Department of Transportation (DOT)	Enhance marine life	Reefs for Marine Life Conservation (P.L. 92-402), National Fishing Enhancement Act of 1984 (P.L. 98-623), 16 U.S.C. 1220-1220d	Use of obsolete ships as artificial reefs for the conservation of marine life
	Enforcement of fisheries laws (U.S. Coast Guard)	(Magnuson) Fishery Conservation and Management Act (P.L. 94-265), 16 U.S.C 1801 et seq.	Enforcement of restrictions on commercial fishing within the fishery conservation zone (Exclusive Economic Zone) (§311)
National Oceanic and Atmospheric Administration (NOAA)	Natural resource trustee for: marine fishery resources and supporting ecosystems; anadromous fish; certain endangered species and marine mammals; National Marine Sanctuaries; and Estuarine Research Reserves	Clean Water Act (P.L. 92-500), 33 U.S.C. 1321(f)(5) Comprehensive Environmental Resppone, Compensation, and Liability Act (P.L. 96-510), 42 V.S.C. 9601 et seq, Oil Pollution Act q1990 (P.L. 101-380), 33 V.S.C. 2701 et seq.	1. Remedial Action Program (CERCLA, §104) 2. NRDA (CERCLA, §107) 3. (OPA, §1006)
	Marine mammals	Marine Mammal Protection Act of 1972 (P.L. 9-522), 16 U.S.C. 1361 et seq.	Prohibition or strict regulation of the direct or indirect taking or importation of marine mammals
	Anadromous Fish	Anadromous Fish Conservation Act of 1965 (P.L. 89-304), 16 U.S.C. 757a-757g	Conservation, development, and enhancement of anadromous fishery resources
		Salmon & Steelhead Conservation and Enhancement Act of 1980 (P.L. 96-561) 16 U.S.C. 3301-3345	Management and enhancement of salmon and steelhead stocks
	Threatened and endangered species and their critical habitats	Endangered Species Act of 1973 (P.L. 93-205), 16 U.S.C. 1531 et seq.)	Insurance that any action authorized, funded, or carried out by any Federal agency is not likely to jeopardize the continued existence of any endangered or threatened species or result in the destruction or adverse modification

FEDERAL AGENCY	SCOPE OF RESOURCE AND HABITAT MANAGEMENT RESPONSIBILITY	LEGISLATIVE AUTHORITY	POTENTIAL PROGRAMS
			of habitat critical to such species (§7) (covers marine species)
	Marine fisheries	Magnuson Fishery Conservation and Management Act of 1976 (P.L. 94-265) 16 U.S.C. 1801 et seq.	Fishery Management Plans by eight regional Fishery Management Councils
	Marine sanctuaries	Marine, Protection, Research and Sanctuaries Act (Title III) P.L. 92-532), 16 U.S.C. 1431-1439)	National Marine Sanctuaries Program
	Protection of coastal natural resources, including wetlands, floodplains estuaries, beaches, dunes, barrier islands, coral reefs and fish and wildlife and their habitat	Coastal Zone Management Act of 1972 (P.L. 92-583), 16 U.S.C. 451 et seq.	1. Coastal zone management program (§305, 306) 2. Resource Management Improvement Grants (§306A) 3. Federal Consistency Determination (§307) 4. National Estuarine Reserve Program (§315)
Department of the Interior - U.S. Fish & Wildlife Service (USFWS)	National resource trustee for: migratory birds; certain anadromous fish, endangered species, and marine mammals; and certain Federally managed water resources	Clean Water Act (P.L. 92-500), 33 U.S.C 1321 (f)(5)	Remedial Action Program (CERCLA, §104)
	Land and water conservation	Land and Water Conservation Fund Act (P.L. 88-578), 16 U.S.C. 460 I-4-460I-11	Establishment of fund to acquire land, waters, or interests in land or waters to promote outdoor recreation opportunities
	Coastal barrier islands	Coastal Barrier Resources Act of 1982 (P.L. 97-348), 16 U.S.C. 3501-3510	1. Establishment of coastal barrier resources system. 2. Coverage of undeveloped coastal barriers, including associated aquatic habitats
	Threatened and endangered species and their critical habitat	Endangered Species Act of 1973 (P.L. 93-205), 16 U.S.C. 1531-1543	Insurance that any action authorized, funded or carried out by any Federal Agency is not likely to jeopardize the continued existence of any endangered or threatened species or result in the destruction or adverse modification of habitat to such species (§7) (covers nonmarine species)
	Estuarine areas	Estuarine Areas Act (P.L. 90-454), 16 U.S.C. 1221 et seq.	Conservation of estuarine areas
	Fish and wildlife conservation	Fish and Wildlife Coordination Act of 1958 (P.L. 85-624), 16 U.S.C. 661-666c	Consultation when Federal agency or Federal permittee proposes to modify a body of water
		Fish and Wildlife Conservation Act of 1980 (P.L. 96-366), 16 U.S.C. 2901 et seq.	Conservation and promotion of nongame fish and wildlife and their habitats
		National Wildlife Refuge System Administration Act (P.L. 91-135), 16 U.S.C. 668dd	Resource management programs for fish and wildlife habitat
	Wetlands conservation	North American Wetlands Conservation Act (P.L. 101-233)	1. Funding for purchase of critical wetlands in the U.S., Canada and Mexico 2. Matching funds for wetlands conservation projects in North American
Other Department of the Interior (DOI)	Development of outer continental shelf, subject to environmental safeguards	Outer Continental Shelf Lands Act (P.L. 93-627), 43 U.S.C. 1331 et seq.	Responsible for removal of oil and gas platforms in Federal waters including those used as artificial reefs
Council on Environmental Quality (CEQ)	Major Federal actions significantly affecting environmental quality	National Environmental Policy Act (P.L. 91-190), 42 U.S.C. 4321 et seq.	1. Mediate interagency disputes
U.S. Army Corps of	Wetlands protection	Clean Water Act (§404)	Dredge and fill permits

FEDERAL AGENCY	SCOPE OF RESOURCE AND HABITAT MANAGEMENT RESPONSIBILITY	LEGISLATIVE AUTHORITY	POTENTIAL PROGRAMS
Engineers (USACOE)		(P.L. 92-500), 33 U.S.C. 1251 et seq.	
	Wetlands creation	Water Resources Development Act of 1976 (§150) (P.L. 94-587), 42 U.S.C. 1962d-5e	Authority to establish wetland areas as part of an authorized water resources development project
	Beach nourishment	Water Resources Development Act of 1976 (§150) (P.L. 94-587), 42 U.S.C. 1962d-5f)	Authority to utilize suitable dredged material for beach nourishment
	Avoiding obstructions to navigation	Rivers and Harbors Appropriation Act of 1899, 33 U.S.C. 401	Regulation of construction activities in an adjoining navigable water which alter the course condition, location, or capacity of such waters
	Regulation of dredged material ocean dumping	Marine Protection Research and Sanctuaries Act (§103) (P.L. 92-532), 33 U.S.C. 1401 et seq.	1. Issuance of ocean dumping permits (§103) 2. Ocean dumpsite selection (§103)
	Fish and wildlife mitigation	Water Resources Development Act of 1986 (§906) (P.L. 99-622), 33 U.S.C. 2201, 2283	Mitigation of fish and wildlife losses associated with authorized water resources projects, including the acquisition of lands or interests in lands
Food and Drug Administration (FD) and Department of Health and Human Services (DHHS)	Healthfulness of fish and shellfish marketed in interstate commerce	Federal Food, Drug and Cosmetic Act, 21 U.S.C. 301-392	1. Setting standards of quality for foods, including seafood (§401) 2. Setting action levels and tolerances for unavoidable contaminants in foods including seafood (§406)
U.S. Department of Agriculture (USDA)	Wetlands protection	Water Bank Act (P.L. 91-559), 16 U.S.C. 1301, 1311, 1501, 1503	3. Preserve, restore, and improve wetlands; conservation easements

2.5.1 Federal, Legal, and Regulatory Constraints

Exhibit 2.23 provides an extensive, but not exhaustive, catalog of the federal authorities and programs most likely to affect the implementation of a restoration action. The key elements of the federal programs are identified, including the scope of each agencies' responsibilities, legislative authority, and specific program area(s). Any individual restoration action may come within the purview of several federal agencies and programs. These programs range from broad, national programs (e.g., Marine Mammal Protection Act), to geographically limited or species-specific initiatives (e.g., Atlantic Striped Bass Conservation Act). In general, regulatory factors can be segmented by agency for which there are requirements for consultation for formal permits. While this listing is a helpful "checklist," it must be recognized that the ultimate breadth and significance of these and other regulatory factors is highly site- and resource-specific and should not be generalized or assumed.

The following are examples of the federal permits that may be required to implement a preferred restoration strategy:

- The gathering of wild marsh plants or seeds from federal lands requires a permits from the federal agency with management responsibility at the proposed collection sites;

- Subtidal bottom restoration activities involving dredging of sediments, or the capping of contaminated sediments in place, require dredge and fill permits (known as "Section 404" permits) from the U.S. Army Corps of Engineers (USACOE). A distinct permitting process, established by Section 103 of the National Marine Sanctuaries Act, applies to restoration actions that require ocean disposal;

- Restoration alternatives that entail the taking, breeding, or releasing of marine mammals are subjects to the extensive review and permitting requirements of the Marine Mammal Protection Act. In a similar fashion, the Endangered Species Act requires permits when capturing, unintentional taking, breeding, or releasing of endangered resources is involved;

- Restoration actions involving artificial reefs are subject to a USACOE permit associated with the alteration of navigable waters. Artificial reefs could also involve the U.S. Coast Guard if navigation safety issues are involved, the Minerals Management Service if an abandoned oil and gas rig is proposed, or the Maritime Administration if an obsolete U.S. merchant marine vessel is at issue;

- Restoration construction actions involving wetlands adjacent to the territorial seas or waterways and their tributaries are subject to the USACOE permitting process. Restoration alternatives using dike-type devices to control erosion are subjected to this same permitting procedure. In a similar fashion, a new fish hatchery project connected to a navigable waterway requires a USACOE permit; and

- Bioremediation in the coastal zone requires an EPA discharge permit. If the proposed restoration action is considered experimental, there could be substantial delays while the advice of other departments and the scientific community is solicited. For example, in the *Exxon Valdez* experience, it was reported that four months elapsed before the necessary permits for bioremediation were approved (Chianelli, 1992).

A second broad category of regulatory concern typically consists of some form of general consultation with other federal agencies that have statutory jurisdiction or interest over some aspect of the resource. Examples of the range of other federal resource management concerns that may apply to specific resource restoration actions follow:

- The National Estuary Program Office's program created by the Clean Water Act (i.e. Chesapeake Bay Program) has responsibility over actions which would affect environmental quality throughout an estuary;

- The Coastal Barrier Resources Act of 1982 gives DOI authority to restrict development within the Coastal Barrier Resources System (CBRS). Restoration actions involving any of the 452,834 acres in the CBRS require DOI concurrence;

- The Water Resources Development Act, Land and Water Conservation Fund Act, and the Waterbank Act authorize the USACOE, DOI, and Department of Agriculture, to acquire, reserve, restore, or establish conservation easements for wetlands. Off-site wetland restoration actions conducted under these initiatives should be consistent with ongoing local initiatives;

- Marine sanctuaries, national parks, wilderness areas, and national forests are a few examples of special natural resource management areas. Restoration actions in special management areas require the concurrence of the appropriate program office; and

- Fishery restoration actions involving management or restocking may be subject to various fisheries management programs, such as regional Fishery Management Councils, the Salmon and Steelhead Conservation and Enhancement Act, or the Atlantic Salmon Conservation Act.

Many programs with statutory authority over natural resources fall within NOAA, USDA, and DOI, the same agencies actively involved in the damage assessment and restoration planning processes. EPA also has many statutority mandates affecting natural resources. Because of this, an effective interagency review of a draft restoration plan should reflect the necessary inputs from many of the federal programs with an interest in the restoration action. However, there remains a potential range of other federal programs or initiatives with the authority to delay or complicate implementation of a restoration action inconsistent with their statutory authorities.

Exhibit 2.24 indicates whether particular programs have regulatory and management, funding, acquisition, or research authority. The following key explains how an understanding of these federal programs can be used to plan a restoration strategy:

- Regulatory and management programs typically have the authority to directly regulate or permit specific activities;

- Acquisition-type programs may exist in federal offices where parallel restoration and habitat enhancement alternatives are ongoing, synergies may exist from coordinating with these initiatives; and

- Research/monitoring programs are those primarily involved in examination or experimentation. These offices may be both sources of scientific support or have an interest in the research aspect of quasi-experimental restoration actions.

2.5.2 State and Local Legal and Regulatory Constraints

In addition to the above federal programs, restoration actions must also be consistent with an often equally extensive range of state or local regulations. At a general level, many of the state regulatory factors closely track with the above federal programs. For example, many state Departments of Fish and Wildlife follow the guidelines of the U.S. Fish and Wildlife Service. There are also a number of joint state/federal programs, such as the Chesapeake Bay Program, in which federal and state priorities and regulatory initiatives are considered fully integrated through contacts with the appropriate program office. However, there are situations in which state or local regulatory conditions diverge from those in the federal or other states. For example, some states specifically ban dispersant use for cleanup or restoration actions.

There are also a variety of state or local permitting programs. Because of the large number of permutations among the various states and hundreds of coastal counties, permitting factors related to restoration at this level are not presented in this document.

Exhibit 2.24 Focus of federal program roles potentially affecting implementation of restoration.

Resource	Legislative Program	Lead Agency	Management / Regulatory	Funding	Acquisition	Research/ Monitoring	Likely Significance to Restoration
Fish	Anadromous Fish Conservation Act	NOAA USFWS	X	X	X	X	
	Salmon & Steelhead Conservation & Enhancement Act	NOAA	X		X	X	
	Magnuson Fishery Conservation and Management Act	NOAA	X	X			
	National Fishing Conservation and Management Act	NOAA	X	X			
	Fish Restoration and Management Project Act	USFWS		X			X
	Atlantic Salmon Conservation Act of 1982 (P.L. 97-389), 16 U.S.C. 3601-3608	NOAA	X				
	Atlantic Striped Bass Conservation Act (P.L. 89-304), 16 U.S.C. 757 g	USFWS		X		X	
Shellfish	National Shellfish Sanitation Program, 16 U.S.C. 1642nt	FDA	X			X	
Mammals	Marine Mammal Protection Act	NOAA	X	X		X	X
	Fur Seal Act	NOAA	X			X	
Waterfowl and Other Birds	Migratory Bird Conservation Act	USFWS	X		X		X
Wetlands	North American Wetlands Conservation Act	USFWS		X	X		X
	Water Resources Development Act (Wetlands Creation)	USACOE	X		X		X
	Water Bank Act	USDA	X	X	X		X
Estuarine Areas	Clean Water Act (National Estuary Program)	EPA	X	X		X	
	Coastal Zone Management Act (National Estuarine Reserve Program)	NOAA	X	X	X	X	
Barrier Islands	Coastal Barriers Resources Act, 16 U.S.C. 3501-3510	USFWS	X				
Marine Sanctuaries	National Marine Sanctuaries Act	NOAA	X	X			
Surface Waters, Wetlands, and Aquatic Biota	Clean Water Act	EPA USACOE (*404)	X			X	X
Ocean Water and Marine Biota	Marine Protection, Research, and Sanctuaries Act (Title I)	EPA USACOE	X			X	
Coastal Resources	Coastal Zone Management Act	NOAA	X	X			
Water and Resources of the Outer Continental Shelf	Outer Continental Shelf Lands Act, 43 U.S.C. 1331-1356	Minerals Management Service	X	X		X	
Endangered Species and Their Critical Habitat	Endangered Species Act	USFWS NOAA	X	X		X	

Fish and Wildlife and Their Habitat	Fish and Wildlife Coordination Act	USFWS	X			X	
Safety of Commercially Marketed Fish and Shellfish Products	Food, Drug & Cosmetic Act	FDA	X				